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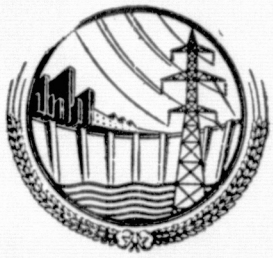
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WATER RESOURCES INVESTIGATION IN PAKISTAN WITH THE HELP OF ERTS IMAGERY-SNOW SURVEYS 1975-76

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LAHORE

March 1978

WATER RESOURCES INVESTIGATION IN PAKISTAN WITH THE HELP OF ERTS IMAGERY-SNOW SURVEYS 1975-76

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In Association with SUPARCO and NASA
Lahore.

March 1978

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C O N T E N T S

	Page
INTRODUCTION	1
STUDY AREA & DATA SOURCES	3
METHOD	9
RESULTS & DISCUSSION	11
CONCLUSION	12
ACKNOWLEDGEMENTS	13
REGRESSION ANALYSIS	14

-x-c-x-

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ILLUSTRATIONS

Figure 1 - Map showing Project Area

Figure 2 - Swat River Sub-basin

Figure 3 - Chitral River Sub-basin

Figure 4 - Kunhar River Sub-basin (Naran)

Figure 5 - Indus River Sub-basin (Besham)

Figure 6 - Kishanganga River Sub-basin

Figure 7 - Jhelum River Sub-basin

Figure 8 - Hunza River Sub-basin

Figure 9 - Gilgit River Sub-basin (Gilgit)

Figure 10 - Kunhar River Sub-basin (G.H. Ullah)

Figure 11 - Gilgit River Sub-basin (Alam Bridge)

Figure 12 - Shyok River Sub-basin

Figure 13 - Indus River Sub-basin (Kachura)

Figure 14 - Indus River Sub-basin (Partab Bridge)

Figure 15 - Astore River Sub-basin (Doyian)

Figure 16 - Average Snow - Cover depletion and run-off curves for Swat River at Kalam 1975 & 1976.

Figure 17 - Average snowcover depletion and run-off curves for Chitral River at Chitral 1975 & 1976.

Figure 18 - Average snowcover depletion & runoff curves for Hunza River at Dainyor Br. 1975 & 1976.

Figure 19 - Average snowcover depletion & runoff curves for Gilgit River at Alam Br. 1975 & 1976.

Figure 20 - Average snowcover depletion & run-off curves for Astore River at Doyian 1976.

Figure 21 - Average snowcover depletion and runoff curves for Kishanganga River at M. Abad 1975 & 1976.

Figure 22 - Average snowcover depletion & runoff curves for Kunhar River at Naran 1975 & 1976.

Figure 23 - Average snowcover depletion & runoff curves for Kunhar River at G.H. Ullah 1976.

Figure 24 - Average snowcover depletion & runoff curves for Jhelum River at Kohala 1975 & 1976.

Figure 25 - Average snowcover depletion & runoff curves for Shyok River at Yogo 1976.

Figure 26 - Average snowcover depletion & runoff curves for Indus River at Kachura 1976.

Figure 27 - Average snowcover depletion & runoff curves for Indus River at Partab Br. 1976.

Figure 28 - Average snowcover depletion & runoff curves for Indus River at Basham Qila 1976.

Figure 29 - Average snowcover depletion & runoff curves for Gilgit River at Gilgit 1975 & 1976.

Figure 30 - Regression Line Group - I 1975 & 1976.

Figure 31 - Regression Line Group - II 1975 & 1976.

Figure 32 - Regression Line Group -III 1975 & 1976.

Figure 33 - Regression Line Group - IV 1975 & 1976.

-x-c-x-

WATER RESOURCES INVESTIGATION IN PAKISTAN WITH THE HELP OF ERTS IMAGERY - SNOW SURVEYS

Chapter-1

I N T R O D U C T I O N

Rivers of the Indus Basin rise in the mountains ranging from 8,500 meters to 10,000 meters in elevation. These mountains are covered with snow during winter (January through March). The snow start melting towards the end of March in some basins, towards the middle of April in others and continues through the summer. During this period the river flows comprise mostly the snow melt run-off. If we are able to predict with some accuracy the flows beginning the end of melt period through the remaining months of the year, we can plan the reservoir operations and canal system operations with some confidence on rational basis. Such predictions are possible only :-

a) If snow surveys are made every year.

b) Flood forecasts are made on dependable basis.

c) Lean periods are covered with the help of regression curve and regeneration in the river system.

The ground methods of snow surveys are expensive, time consuming and difficult. Luckily with the advent of land-satellites, it has become possible to map the earth's surface

...2

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at fixed intervals. Land-sat 2 scans the earth every 18 days; there are other satellites in the orbit at varying distances from the earth. These satellites produce high resolution images of the earth's surface which when interpreted properly give the area of snow cover, the river course and an idea of the river stages with respect to time. The snow covered area can be calculated with snow melt runoff at desired points. This can give a base for predicting the snow-melt runoff.

River flows during high flow period of the year (monsoon and conventional storms of winter) can be separately determined through stream gauging processes.

The present report is an attempt to combine the results of land-satellite 2 imagery for the year 1975 and 1976 (April through August) and derive a base for the snow melt runoff predictions April through August. Runoff predictions during the remaining period of the year is subject matter of another study which is being conducted separately with the cooperation of UNESCO. A report of that study shall be published in due course. Two important improvements have been made in this report over the previous one :

1) The snow covered area has been divided into groups of basins with similar characteristics.

2) Area has been calculated into blocks one square mile in extent and has been equated to the total runoff April through August.

Chapter - 2

STUDY AREA AND DATA SOURCES

WAPDA entered into an Agreement with NASA (National Aeronautics and Space Administration), through SUPARCO (Pakistan Space and Upper Atmosphere Research Committee) in May 1975 - "29810, Water Resources Investigation in West Pakistan with the help of ERTS Imagery - Snow Surveys". Under this agreement NASA had to supply Land-Sat 2 Imagery of the project area beginning January 1975. The project area is bounded by the coordinates 33°.00N to 37°.00N and 71°.00E to 78°.00E (Figure-1). So far NASA has supplied from February to June, 1975 and April to August 1976, the following imagery :-

LIST OF 1975 IMAGERY

Sl. No.	Scene ID No.	Date	Centre Point		Band
			Lat. N	Long. E	
1	2	3	4	5	6
1.	2023-04554	14-2	34°-31'	75°-20'	4,5
2.	2025-05071	16-2	34°-28'	72°-25'	4,5,7
3.	2025-05064	16-2	35°-54'	72°-52'	4,5,7
4.	2025-05062	16-2	37°-20'	73°-19'	4,5
5.	2026-05125	17-2	34°-29'	70°-59'	4,5,7
6.	2026-05123	17-2	35°-55'	71°-25'	4,5,7
7.	2026-05120	17-2	37°-21'	71°-53'	4,5,7
8.	2040-04501	3-3	33°-13'	76°-19'	4,5,7
9.	2040-04495	3-3	34°-39'	76°-46'	4,5,7
10.	2043-05070	6-3	34°-34'	72°-26'	4,5,7
11.	2044-05122	7-3	35°-56'	71°-26'	4,5,7

...4

1	2	3	4	5	6
12.	2044-05120	7-3	37°-22'	71°-54'	4,5,7
13.	2061-05065	24-3	34°-31'	72°-26'	4,5,7
14.	2061-05062	24-3	35°-57'	72°-54'	4,5,7
15.	2061-05060	24-3	37°-23'	73°-21'	4,5,7
16.	2062-05213	25-3	34°-31'	71°-01'	4,5,7
17.	2062-05121	25-3	35°-57'	71°-27'	4,5,7
18.	2062-05114	25-3	37°-22'	71°-55'	4,5,7
19.	2077-04552	9-4	34°-33'	75°-14'	4,5,7
20.	2078-05010	10-4	34°-32'	73°-54'	4,5,7
21.	2078-05004	10-4	35°-58'	74°-21'	4,5,7
22.	2079-05065	11-4	34°-29'	72°-26'	4,5,7
23.	2079-05062	11-4	35°-55'	72°-53'	4,5,7
24.	2079-05060	11-4	37°-21'	73°-21'	4,5,7
25.	2080-05123	12-4	34°-28'	70°-53'	4,5,7
26.	2095-04545	27-4	35°-52'	75°-70'	4,5,7
27.	2095-04543	27-4	37°-17'	76°-07'	4,5,7
28.	2096-05010	28-4	34°-26'	73°-48'	4,5,7
29.	2096-05004	28-4	35°-51'	74°-14'	4,5,7
30.	2096-05001	28-4	37°-17'	74°-42'	4,5,7
31.	2098-05114	30-4	37°-10'	71°-45'	4,5,7
32.	2116-05121	18-5	34°-23'	70°-57'	4,5,7
33.	2116-05115	18-5	35°-49'	71°-23'	4,5,7
34.	2130-04495	1-6	32°-59'	76°-09'	4,5,7
35.	2131-04552	2-6	34°-33'	75°-14'	4,5,7
36.	2131-04545	2-6	35°-47'	75°-35'	4,5,7
37.	2131-04545	2-6	35°-47'	75°-35'	4,5,7
38.	2132-05010	3-6	34°-18'	73°-42'	4,5,7
39.	2132-05001	3-6	37°-10'	74°-35'	4,5,7
40.	2133-05065	4-6	34°-19'	72°-15'	4,5,7
41.	2133-05062	4-6	35°-45'	72°-42'	4,5,7
42.	2148-04500	19-6	33°-03'	76°-08'	4,5,7
43.	2149-04550	20-6	35°-56'	75°-34'	4,5,7
44.	2149-04543	20-6	37°-22'	76°-07'	4,5,7
45.	2150-05002	21-6	37°-19'	74°-35'	4,5,7

1	2	3	4	5	6
46.	2151-05060	22-6	37°-21'	73°-10'	4,5,7
47.	2152-05124	23-6	34°-27'	70°-48'	4,5,7
48.	2152-05121	23-6	35°-53'	71°-15'	4,5,7
49.	2152-05115	23-6	37°-18'	71°-42'	4,5,7

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LIST OF 1976 IMAGERY

Sl. No.	Scene ID No.	Date	Centre Point		Band
			lat.N	Long.E	
1	2	3	4	5	6
1.	2383-04530	9-2	32°-50'	74°-36'	4,5,6,7
2.	2383-04523	9-2	34°-15'	75°-04'	"
3.	2383-04521	9-2	35°-41'	75°-27'	"
4.	2383-04514	9-2	37°-06'	75°-55'	"
5.	2384-04581	10-2	34°-15'	73°-45'	"
6.	2401-04520	27-2	34°-38'	75°-25'	"
7.	2401-04523	27-2	32°-45'	74°-46'	"
8.	2402-04581	28-2	33°-10'	73°-15'	"
9.	2402-04574	28-2	34°-30'	74°-15'	"
10.	2403-05033	29-2	34°-30'	72°-10'	"
11.	2403-05030	29-2	36°-05'	72°-40'	"
12.	2403-05024	29-2	37°-20'	73°-15'	"
13.	2435-04395	1-4	33°-08'	77°-40'	"
14.	2435-04393	1-4	34°-20'	78°-15'	"
15.	2436-04445	2-4	36°-04'	77°-04'	5,7
16.	2436-04451	2-4	34°-37'	76°-37'	"
17.	2436-04454	2-4	33°-11'	76°-11'	"
18.	2437-04505	3-4	34°-38'	75°-11'	"
19.	2437-04503	3-4	36°-04'	75°-38'	"
20.	2437-04512	3-4	33°-12'	74°-45'	"
21.	2437-04500	3-4	37°-30'	76°-06'	"
22.	2440-05080	6-4	34°-38'	70°-56'	"
23.	2440-05073	6-4	36°-08'	71°-20'	"
24.	2440-05071	6-4	37°-32'	71°-50'	"
25.	2454-04450	20-4	33°-20'	76°-16'	"
26.	2455-04493	21-4	37°-35'	76°-10'	"
27.	2455-04495	21-4	36°-09'	75°-42'	"
28.	2455-04502	21-4	34°-43'	75°-15'	"
29.	2455-04504	21-4	33°-16'	74°-49'	"
30.	2456-04563	22-4	33°-15'	73°-23'	"

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1	2	3	4	5	6
31.	2456-04560	22-4	34°-42'	73°-49'	5,7
32.	2456-04554	22-4	36°-08'	74°-16'	"
33.	2456-04551	22-4	37°-34'	74°-44'	"
34.	2457-05005	23-4	37°-31'	73°-15'	"
35.	2467-05012	23-4	36°-05'	72°-47'	"
36.	2467-05014	23-4	34°-40'	72°-21'	"
37.	2472-04434	8-5	36°-04'	77°-07'	"
38.	2472-0441	8-5	34°-38'	76°-40'	"
39.	2472-04443	8-5	33°-13'	76°-14'	"
40.	2473-04493	9-5	36°-03'	75°-39'	"
41.	2473-04495	9-5	34°-37'	75°-12'	"
42.	2473-04502	9-5	33°-11'	74°-46'	"
43.	2474-04544	10-5	37°-31'	74°-41'	"
44.	2474-04551	10-5	36°-05'	74°-14'	"
45.	2474-04553	10-5	34°-38'	73°-47'	"
46.	2474-04560	10-5	33°-12'	73°-21'	"
47.	2474-05003	11-5	37°-29'	73°-16'	"
48.	2475-05005	11-5	36°-04'	72°-49'	"
49.	2475-05012	11-5	34°-37'	72°-22'	"
50.	2490-04434	26-5	34°-32'	76°-35'	"
51.	2490-04441	26-5	33°-05'	76°-10'	"
52.	2491-04483	27-5	37°-22'	76°-03'	"
53.	2491-04490	27-5	35°-56'	75°-36'	"
54.	2491-04492	27-5	34°-31'	75°-09'	"
55.	2491-04495	27-5	33°-04'	74°-43'	"
56.	2492-04542	28-5	37°-25'	74°-39'	"
57.	2492-04544	28-5	35°-58'	74°-12'	"
58.	2492-04551	28-5	34°-32'	73°-45'	"
59.	2493-05000	29-5	37°-24'	73°-11'	"
60.	2493-05002	29-5	35°-59'	72°-44'	"
61.	2493-05005	29-5	34°-35'	72°-17'	"
62.	2494-05061	30-5	35°-57'	71°-17'	"
63.	2494-05063	30-5	34°-30'	70°-50'	"
64.	2508-04425	13-6	35°-56'	77°-01'	"

1	2	3	4	5	6
65.	2508-04432	13-6	34°-30'	76°-34'	5,7
66.	2508-04434	13-6	33°-04'	76°-08'	"
67.	2509-04481	14-6	37°-02'	76°-02'	"
68.	2509-04483	14-6	35°-55'	75°-35'	"
69.	2509-04490	14-6	34°-29'	75°-09'	"
70.	2510-04542	15-6	35°-54'	74°-09'	"
71.	2510-04544	15-6	34°-29'	73°-43'	"
72.	2511-04593	16-6	37°-20'	73°-10'	"
73.	2511-05000	16-6	35°-54'	72°-.3'	"
74.	2511-05002	16-6	34°-28'	72°-17'	"
75.	2512-05054	17-6	35°-52'	71°-15'	"
76.	2512-05061	17-6	34°-26'	70°-49'	"
77.	2525-04370	30-6	34°-31'	78°-01'	"
78.	2543-04363	18-7	34°-31'	78°-03'	"
79.	2543-04370	18-7	33°-08'	77°-36'	"
80.	2545-04471	20-7	37°-24'	76°-03'	"
81.	2545-04473	20-7	35°-57'	75°-35'	"
82.	2545-04480	20-7	34°-31'	75°-09'	"
83.	2546-04525	21-7	37°-24'	74°-38'	"
84.	2546-04532	21-7	35°-59'	74°-10'	"
85.	2548-05044	23-7	35°-58'	71°-19'	"
86.	2563-04470	7-8	26°-04'	75°-38'	"
87.	2564-04522	8-8	37°-31'	74°-41'	"
88.	2564-04524	8-8	36°-06'	74°-13'	"
89.	2565-04580	9-8	37°-28'	73°-13'	"
90.	2565-04585	9-8	34°-37'	72°-19'	"
91.	2566-05041	10-8	36°-04'	71°-19'	"
92.	2581-04463	25-8	36°-08'	75°-38'	"
93.	2581-04465	25-8	34°-42'	75°-11'	"
94.	2583-04573	27-8	37°-29'	73°-13'	"
95.	2583-04575	27-8	36°-04'	72°-45'	"

Only this imagery has been analysed and used for this report. Imagery for the snow season 1977 has been received from NASA and is yet to be interpreted.

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M E T H O D

The images were put through Colour Additive Viewer and the Zoom Transfer-scope and the workable images were seperated. The Indus Basin was then divided into 14 sub basins given below and shown in figures 2 to 15.

		Drainage Area
1.	Swat River near Kalam	780 Sq.mi.
2.	Chitral River at Chitral	4,400 Sq.mi.
3.	Kunhar River at Naran	400 Sq.mi.
4.	Indus River at Besham	62,700 Sq.mi.
5.	Kishan-Ganga River at Muzaffarabad	2,810 Sq.mi.
6.	Jhelum River at Kohala	9,610 Sq.mi.
7.	Hunza River at Dainyor Bridge	5,080 Sq.mi.
8.	Gilgit River at Gilgit	4,670 Sq.mi.
9.	Kunhar River at G.H. Ullah	920 Sq.mi.
10.	Gilgit River at Alam Bridge	10,100 Sq.mi.
11.	Shyok River at Yogo	13,000 Sq.mi.
12.	Indus River at Kachura	43,500 Sq.mi.
13.	Indus River at Partab Bridge	55,100 Sq.mi.
14.	Astore River at Doyian	1,560 Sq.mi.

With the help of Zoom Transfer-scope and Colour Additive Viewer, overlays of all the sub basins were prepared for each day of the available images. On these overlays snow covered area was marked in colour and was calculated with a planimeter. Eighteen days per square mile river flows were tabu-

lated. The percent snow-covered area and eighteen days per square mile river flows were plotted on a time base. These plots have been shown in Figures 16 to 29.

The two years data from Land-Sat 2 Imagery for 1975-76 were combined. Close examination of the data and the runoff snow melt hydrographs indicate that the Indus Basin can be grouped into four parts, each part having definite characteristics.

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RESULTS AND DISCUSSION

An examination of Figures 16 to 29 reveals that the snow increases as we travel from South to North. The snow starts melting earlier on the Southern latitudes and stays longer on the Northern latitudes. On the Southern latitudes the snow starts melting towards the middle of February whereas in the Northern latitudes the melting starts generally towards the end of March. Higher mountain peaks are encountered as we travel from South to North. In general, it can be assumed that the snow melt starts about the first of April. By the end of June about 50% of the basin becomes free of snow. The remaining 50% of the snow cover keeps melting through the summer. Towards the end of August a recession starts in the snow melt hydrographs till it hits the base flow towards the end of October.

A regression equation of the type $R = aA + b$ with R and A being the runoff in Million Acre-feet from April to August and area under snow in 1000 sq. miles on 1st of April respectively for the years 1975 & 1976 has been attempted which shows encouraging results (Figure 30 to 33). The equations derived from the analysis of two years data are given below :-

i) $R = 1.075\ A + 0.847$
ii) $R = 1.951\ A + 0.208$
iii) $R = 0.799\ A - 5.925$
iv) $R = 1.140\ A + 1.355$

Since the regression is based on only two seasons data, it is expected to change. However, with four to five years of data a firm equation is expected to emerge.

...12

CONCLUSION

Figures 16 to 29 indicate that a relationship exists between the snow covered area per square mile on a particular date and the resulting snow melt runoff during the subsequent period. It was not possible to measure the snow depth and water equivalent of the snow pack in the form of a linear regression equation of the type $R = aA + b$.

The confidence level represented by $r^2 = 0.976$ for 1975 data is equal to constant and is given below for the four groups. Subsequently four regression curves have been derived. It can be said with confidence that level shall remain within tolerable limits. However, more data would be necessary to confirm this assumption.

The four particular equation of the four groups are reproduced below :-

Group No.	Regression Equation	Value of r^2
I	$R = 1.075\ A + 0.847$	$r^2 = 0.972$
II	$R = 1.951\ A + 0.208$	$r^2 = 0.865$
III	$R = 0.799\ A - 5.925$	$r^2 = 0.893$
IV	$R = 1.140\ A + 1.355$	$r^2 = 0.738$

Where R = April - August Snow Melt Run-off in MAF.

A = Area Under Snow on 1st of April in 1000 sq.miles.

The equation based on one year landsat data of 1975 which was presented in the previous report is given below :-

$R = 1.02\ A + 1.11$ and $r^2 = 0.976$.

...13

ACKNOWLEDGEMENTS

The authors are grateful to NASA for providing financial support and to EROS Data Centre for sending the imagery. The authors are also grateful for the help SUPARCO provided by way of handling the correspondence and by making their instruments available for interpretation. The authors are grateful to Surface Water Hydrology Project of Hydrology And Investigation Organization for supplying the run-off data. The authors are in particular grateful to Sh. Mohammed Hussain, Co-Investigator and Ch. Sana Ullah, Senior Research Officer, who spent long hours on the interpretation of the images. Thanks are also due to the ministerial and drafting staff of Hydrology & Investigation Organization who provided necessary help. At the end the Principal Investigator is grateful to Mr. Rango who has very kindly supplied results of his own studies whenever requested.

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REGRESSION ANALYSIS

GROUP NO.1

Sl. No.	Name of Station	Catch-ment Area Sq.mi.	Snow Area in Sq.mi. on 1st Apr 1975&1976	RUN OFF IN 10^6 ACRE - FEET						Direct Rain-Fall	Snow Melt
				APR:	MAY	JUN:	JUL:	AUG:	Total		
1.	Swat River near Kalam	780	745	.091	.396	.565	.543	.485	2.080	0.350	1.730
2.	Swat River near Kalam		698	.058	.315	.522	.663	.373	1.931	0.401	1.530
3.	Chitral River at Chitral	4,400	4206	.199	.408	1.050	1.630	1.740	5.027	-	5.027
4.	Chitral River at Chitral		4224	.191	.422	.857	1.760	1.510	4.740	-	4.740
5.	Hunza River at Dainyor Bridge.	5,080	4724	.110	.303	.976	2.046	2.734	6.169	-	6.169
6.	Hunza River at Dainyor Bridge		4343	.096	.425	1.020	3.290	1.950	5.781	-	6.781
7.	Gilgit River at Alam Bridge	10,100	9010	.204	.613	2.015	3.389	3.803	10.024	-	10.024
8.	Gilgit River at Alam Bridge		8989	.197	.747	2.010	4.450	3.380	10.784	-	10.784
9.	Astore River at Doyian	1,560	1525	.082	.365	0.556	.734	.459	2.196	-	2.196

Sl. No.	X Area under snow 10^3 Sq.mile on 1st April	Y Run-off April-August 10^6 Acre-feet	XY	X^2
1.	0.745	1.730	1.289	0.555
2.	0.698	1.530	1.068	0.487
3.	4.206	5.027	21.144	17.690
4.	4.224	4.740	20.022	17.842
5.	4.724	6.169	29.142	22.316
6.	4.343	6.781	29.450	18.862
7.	9.010	10.024	90.316	81.180
8.	8.989	10.784	96.937	80.802
9.	1.525	2.196	3.349	2.326
Total :-	38.464	48.981	292.717	242.060
	$\bar{X}$ = 4.274	$\bar{Y}$ = 5.442	$\bar{XY}$ = 23.259	$\bar{X}^2$ = 18.267

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15

MIC

GROUP - I

Sl. No.	$X_o = X - \bar{X}$	$Y_o = Y - \bar{Y}$	$X_o Y_o$	X_o^2	Y_o^2
1.	- 3.529	- 3.712	13.100	12.454	13.779
2.	- 3.576	- 3.912	13.989	12.788	15.304
3.	- 0.068	- 0.415	0.028	0.005	0.172
4.	- 0.050	- 0.702	0.035	0.003	0.493
5.	+ 0.450	+ 0.727	0.327	0.203	0.529
6.	+ 0.069	+ 1.339	0.092	0.005	1.793
7.	+ 4.736	+ 4.582	21.700	22.430	20.995
8.	+ 4.715	+ 5.342	25.188	22.231	28.537
9.	- 2.749	- 3.246	8.923	7.557	10.537
Total :-			$E_{X_oY_o}$=83.382	$E_{X_o^2}$= 77.676	$E_{Y_o^2}$=92.139

REGRESSION EQUATION

$Y = a + bx$

$$b = \frac{E\, x_i y_i - N\, \bar{x}\, \bar{y}}{E\, x_i^2 - N\, \bar{x}^2}$$

$a = \bar{Y} - b\, \bar{x}$

$$b = \frac{292.817 - 9(23.259)}{242.060 - 9(18.267)} = 1.075$$

$a = 5.442 - (1.075)(4.274) = 0.847$

$Y = 0.847 + 1.075\, X$

$R = 0.847 + 1.075\, A$

R -- Snow melt runof in 10^6 Acre-feet.
(April-Augu)

A -- Area under snow n 10^3 Sq.mi. on first of April.

$$r = \frac{E_{x_o y_o}}{\sqrt{E(x_o^2) \times E(y_o^2)}} = \frac{83.382}{\sqrt{(77.676)(92.139)}}$$

$= 0.986$

$r^2 = 0.972$

-x-c-x-

...16

REGRESSION ANALYSIS

GROUP NO.II

Sl No.	Name of Station	Catch-ment Area Sq.mi.	Snow Area in Sq.mi. on 1st Apr 1975&1976	RUN OFF IN 10^6 ACRE FEET							
				APR:	MAY	JUN:	JUL:	AUG:	Total	Direct Rain-Fall	Snow Melt
1.	Kishanganga River at Muzaffarabad	2810	2127	.403	.880	.948	.755	.523	3.509	-	3.509
2.	Kishanganga River at Muzaffarabad		2500	.953	1.900	1.800	1.570	1.160	7.383	.705	6.678
3.	Kunhar River at Naran	400	384	.042	.215	.298	.230	.146	.931	-	0.931
4.	Kunhar River at Naran		384	.037	.173	.268	.283	.149	.910	-	0.910
5.	Kunhar River at G.H.Ullah	920	639	.099	.343	.505	.509	.357	1.813	.313	1.500
6.	Jhelum River at Kohala	9610	4910	1.093	1.820	1.771	1.858	1.593	8.135	1.250	6.885
7.	Jhelum River at Kohala		5507	2.430	3.540	3.170	2.680	3.010	14.830	1.708	13.122

Sl. No.	X Area under snow 10^3 Sq. Mile on 1st April	Y Run-off April-August 10^6 Acre-feet.	XY	X^2
1.	2.127	3.509	7.464	4.524
2.	2.500	6.678	16.695	6.250
3.	0.384	0.931	0.358	0.147
4.	0.384	0.910	0.349	0.147
5.	0.639	1.500	0.959	0.408
6.	4.901	6.885	33.743	24.020
7.	5.507	13.122	72.263	30.327
Total:	16.442	33.535	131.831	65.823
	$\bar{X}$ = 2.349	$\bar{Y}$ = 4.791	$\overline{XY}$ = 11.254	$\overline{X^2}$ = 5.518

GROUP - II

Sl. No.	$X_o = X_i - \bar{X}$	$Y_o = Y_i - \bar{Y}$	$X_o Y_o$	X_o^2	Y_o^2
1.	- 0.282	- 1.282	0.285	.049	1.644
2.	0.151	1.887	0.285	.023	3.561
3.	- 1.965	- 3.860	7.585	3.861	14.900
4.	- 1.965	- 3.881	7.626	3.861	15.062
5.	- 1.710	- 3.291	5.628	2.924	10.831
6.	2.552	2.094	5.344	6.513	4.385
7.	3.158	8.331	26.309	9.973	69.406
		Total :-	53.062	27.204	119.789

REGRESSION EQUATION

$$Y = a + bx$$

$$b = \frac{E\, x_i y_i - N\, \bar{x}\, \bar{y}}{E\, x_i^2 - N\, \bar{x}^2}$$

$$a = \bar{Y} - b\, \bar{x}$$

i.e $$b = \frac{131.831 - 7 \times 11.254}{65.823 - 7 \times 5.518} = \frac{53.059}{27.197} = 1.951$$

$$a = 4.791 - 1.951 \times 2.349 = 4.791 - 4.583 = 0.208$$

i.e $y = 0.208 + 1.951\, X$

or $R = 0.208 + 1.951\, A$

R - Snow melt runoff in 10^6 Acre-feet (April-August)

A - Area under snow in 10^3 Sq. mile on 1st of April

$$r = \frac{E\, x_o\, y_o}{\sqrt{E(x_o)^2 + E(y_o^2)}} = \frac{53.062}{\sqrt{27.204 \times 119.784}} = \frac{53.062}{57.084}$$

$r = 0.930$

$r^2 = 0.865$

-x-c-x-

...18

REGRESSION ANALYSIS

GROUP NO.III

Sl. No.	Name of Station	Catch-ment Area Sq.mi.	Snow Area in Sq.mi. on 1st Apr: 1975&1976	RUN-OFF IN 10^6 ACRE FEET							
				APR:	MAY	JUN:	JUL:	AUG:	Total	Direct Rain-Fall	Snow Melt
1.	Shyok River at Yogo	13000	11440	.112	.232	.626	2.840	1.780	5.590	-	5.590
2.	Indus River at Kachura	43500	40455	.494	1.540	3.150	7.870	5.140	18.194	-	18.194
3.	Indus River at Partab Bridge	55100	51023	.736	2.850	6.180	14.000	10.200	33.966	-	33.966
4.	Indus River at Besham Qila	62700	55400	1.620	3.990	11.000	13.700	15.700	46.010	5.000	41.010
5.	Indus River at Besham Qila		49972	1.780	4.790	8.950	17.200	12.100	43.820	5.780	38.040

Sl. No.	X Area under snow 10^3 Sq.Mile on 1st April	Y Run-off April-August 10^6 Acre-Feet	XY	X^2
1.	11.440	5.590	63.950	130.874
2.	40.455	18.194	736.038	1636.607
3.	51.023	33.966	1733.047	2603.347
4.	55.400	41.010	2271.954	3069.160
5.	49.972	38.040	1900.935	2497.201
Total:	208.290	136.800	6705.924	9937.189

$\overline{X}$ = 41.658 $\overline{Y}$ = 27.360 $\overline{XY}$ = 1139.763 $\overline{X}^2$ = 1735.389

MIC

...19

GROUP - III

Sl. No.	$X_o = X_1 - \bar{X}$	$Y_o = Y_1 - \bar{Y}$	$X_o Y_o$	X_o^2	Y_o^2
1.	- 30.218	-21.770	657.846	913.128	473.933
2.	- 1.203	- 9.166	11.027	1.447	84.016
3.	9.365	6.606	61.865	87.703	43.639
4.	13.742	13.650	187.578	188.843	186.323
5.	8.314	10.680	88.794	69.123	114.062
		Tc al :-	1007.110	1260.244	901.973

REGRESSION EQUATION

$$Y = a + bx$$

$$b = \frac{E\, X_1\, Y_1 - N\, \bar{X}\, \bar{Y}}{E\, x_1^2 - N\, \bar{x}^2}$$

$$a = \bar{Y} - b\, \bar{x}$$

i.e. $$b = \frac{6705.924 - 5 \times 1139.763}{9937.189 - 5 \times 1735.389} = \frac{1007.109}{1260.244} = 0.799$$

$$a = 27.360 - 0.799 \times 41.658 = 27.360 - 33.285 = - 5.925$$

or $Y = 0.799\, X - 5.925$

$R = 0.799\, A - 5.925$

where R = Snow melt Runoff in 10^6 Acre-feet (April-August)

A = Area under snow in 10^3 Sq. mile on first of April.

$$r = \frac{E\, x_o\, Y_o}{\sqrt{E(x_o)^2 \times (y_o)^2}}$$

$$= \frac{1007.110}{\sqrt{1260.244 \times 901.973}}$$

$$= \frac{1007.109}{1066.164} = 0.945$$

$r^2 = 0.893$

-x-c-x-

REGRESSION ANALYSIS

GROUP NO.IV

Sl. No.	Name of Station	Catch-ment Area Sq.mi.	Snow Area in Sq.mi. on 1st Apr. 1975&1976	RUN-OFF IN 10^6 ACRE FEET							
				APR:	MAY	JUN:	JUL:	AUG:	Total	Direct Rain-Fall	Snow Melt
1.	Swat River at Kalam	780	745	.091	.396	.565	.543	.485	2,080	.350	1.730
2.	Swat River at Kalam		698	.058	.315	.522	.663	.373	1.931	.401	1.530
3.	Chitral River at Chitral	4400	4206	.199	.408	1.050	1.630	1.740	5.027	-	5.027
4.	Chitral River at Chitral		4224	.191	.422	0.857	1.780	1.510	4.740	-	4.740
5.	Hunza River at Dainyor Bridge	5080	4724	.110	.303	.976	2.046	2.734	6.169	-	6.169
6.	Hunza River at Dainyor Bridge		4343	.096	.425	1.020	3.290	1.950	6.781	-	6.781
7.	Gilgit River at Alam Br.	10100	9010	.204	.613	2.015	3.389	3.803	10.024	-	10.024
8.	Gilgit River at Alam Br.		8989	.197	.747	2.010	4.450	3.380	10.784	-	10.784
9.	Astore River at Doyain	1560	1525	.082	.365	.556	.734	.459	2.196	-	2.196
10.	Kunhar River at G. H. Ullah	920	639	.099	.343	.505	.509	.357	1.813	.313	1.500
11.	Kishanganga River at Muzaffarabad	2810	2127	.403	.880	.948	.755	.523	3.509	-	3.509
12.	Kishanganga River at Muzaffarabad		2500	.953	1.900	1.800	1.570	1.160	7.383	.705	6.678
13.	Jhelum River at Kohala	9610	4901	1.093	1.820	1.771	1.858	1.593	8.135	1.250	6.885
14.	Jhelum River at Kohala		5507	2.430	3.540	3.170	2.680	3.010	14.830	1.708	13.122

...21

Sl. No.	X Area under snow 10^3 Sq. mile on 1st of April	Y Run-off April-August 10^6 Acre-Feet	XY	X^2
1.	0.745	1.730	1.289	0.555
2.	0.698	1.530	1.068	0.487
3.	4.206	5.027	21.244	17.690
4.	4.224	4.740	20.022	17.842
5.	4.724	6.169	29.142	22.316
6.	4.343	6.781	29.450	18.862
7.	9.010	10.024	90.316	81.180
8.	8.989	10.784	96.937	80.802
9.	1.525	2.196	3.349	2.326
10.	0.639	1.500	0.959	0.408
11.	2.127	3.509	7.464	4.524
12.	2.500	6.678	16.695	6.250
13.	4.901	6.885	33.743	24.020
14.	5.507	13.122	72.263	30.327
	E=54.138	E=80.675	E=423.941	E=307.589

$\overline{X} = \underline{3.867}$

$\overline{Y} = 5.763$

$\overline{X}\,\overline{Y} = 22.286$

$\overline{X}^2 = 14.954$

-x-c-x-

MIC

GROUP - IV

Sl. No.	$X_o = X - \bar{X}$	$Y_o = Y - \bar{Y}$	$X_o Y_o$	X_o^2	Y_o^2
1.	- 3.122	- 4.033	12.591	9.747	16.265
2.	- 3.169	- 4.233	13.414	10.043	17.918
3.	0.339	- 0.736	- 0.250	0.115	0.542
4.	0.357	- 1.023	- 0.365	0.127	1.047
5.	0.857	0.406	0.348	0.734	0.165
6.	0.476	1.018	0.485	0.227	1.036
7.	5.143	4.261	21.914	26.450	18.156
8.	5.122	5.021	25.718	26.235	25.210
9.	- 2.342	- 3.567	8.354	5.485	12.723
10.	- 3.228	- 4.263	13.761	10.420	18.173
11.	- 1.740	- 2.254	3.922	3.028	5.081
12.	- 1.367	0.915	- 1.251	1.869	0.837
13.	1.034	1.122	1.160	1.069	1.259
14.	1.640	7.359	12.069	2.690	54.155
		Total :-	111.870	98.239	172.567

REGRESSION EQUATION

$$Y = a + bx$$

$$b = \frac{Ex_1 Y_1 - N \bar{x} \bar{y}}{Ex^2 - N \bar{x}^2}$$

$$= \frac{423.941 - 14\ (22.286)}{307.589 - 14\ (14.954)} = 1.140$$

$$a = \bar{Y} - b \bar{x} = 5.763 - (1.140)\ (3.867) = 1.355$$

$$Y = 1.355 + 1.140\ x$$

$$R = 1.355 + 1.140\ A$$

where R = Snow melt Runoff in 10^6 acre-feet (April-August)

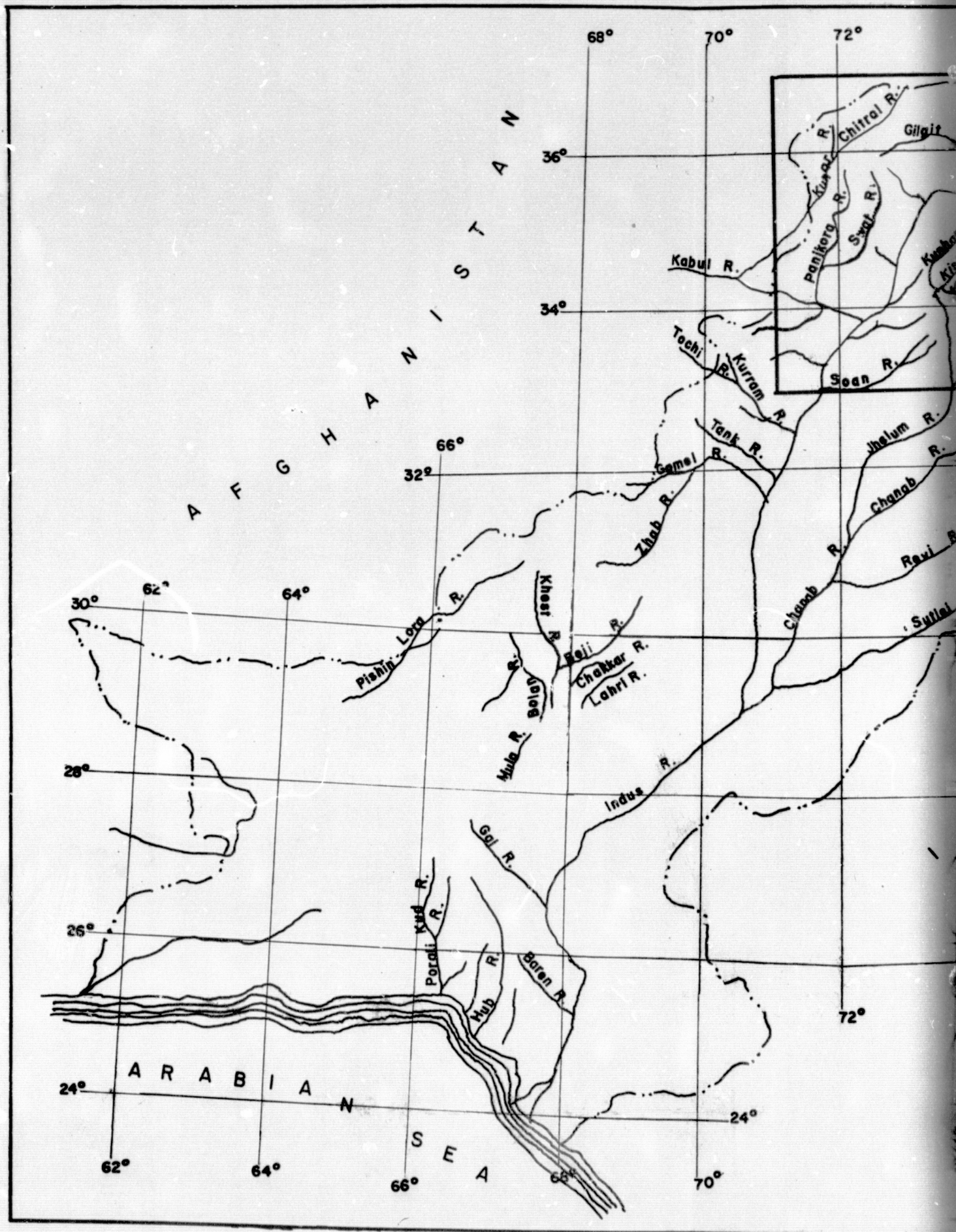
A = Area under snow in 10^3 Sq.mile on first of April.

$$r = \frac{Ex_o\ Y_o}{\sqrt{E(x_o)^2 \times x(y_o)^2}} = \frac{111.870}{\sqrt{(98.239)(172.567)}} = \frac{111.870}{130.203}$$

$$r = 0.859$$

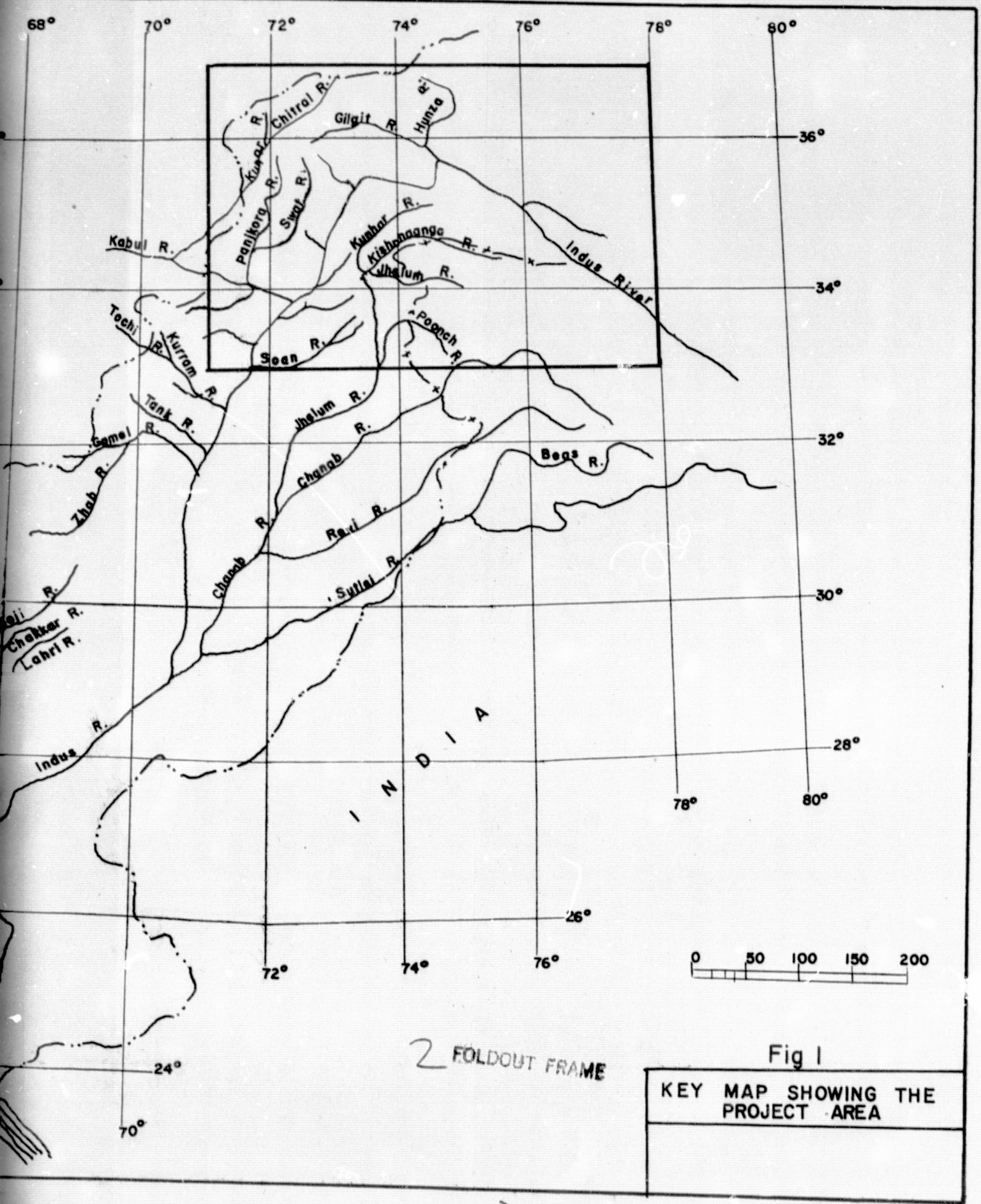
$$r^2 = 0.738$$

-x-c-x-



FOLDOUT FRAME 1

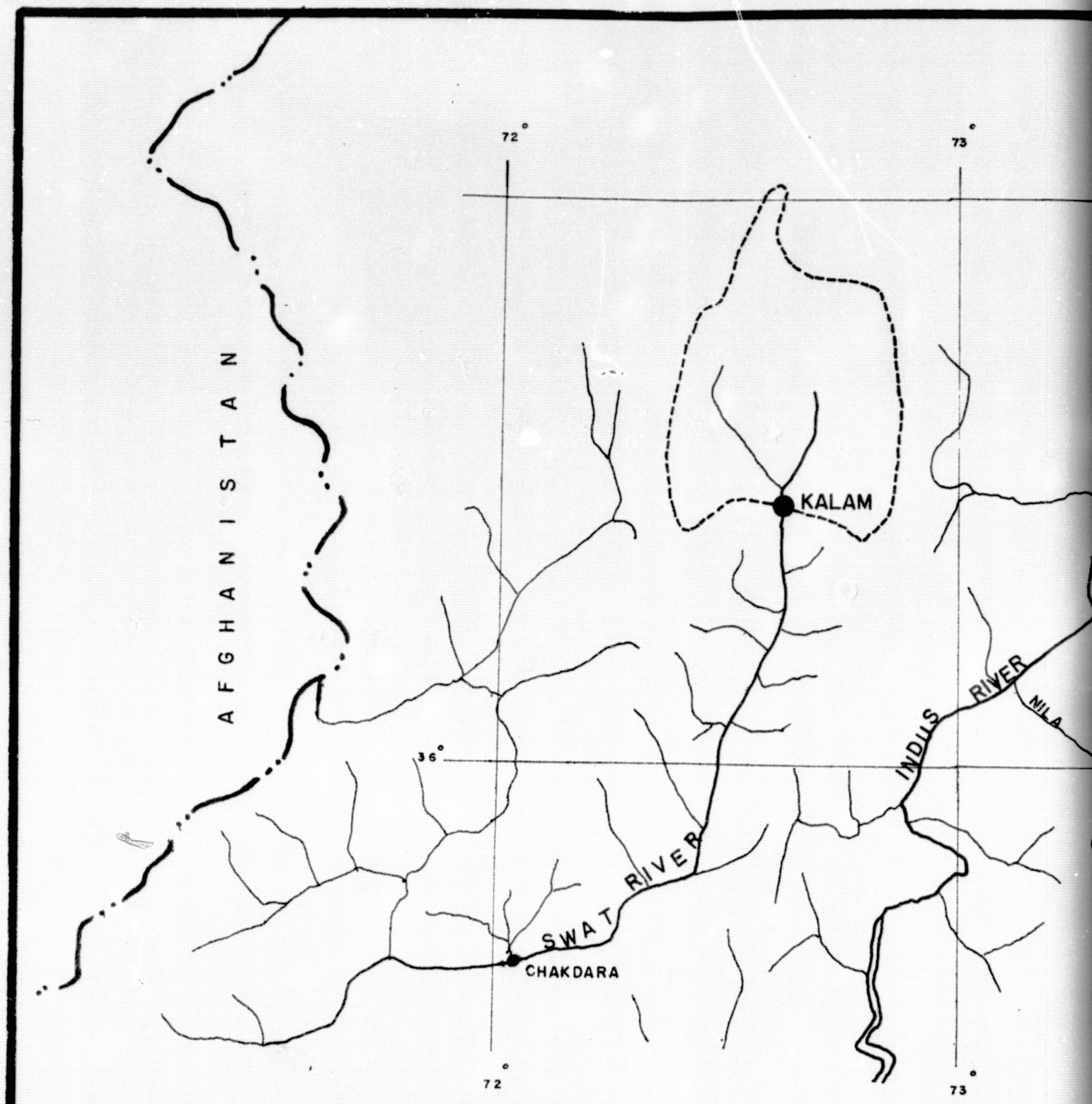
22A



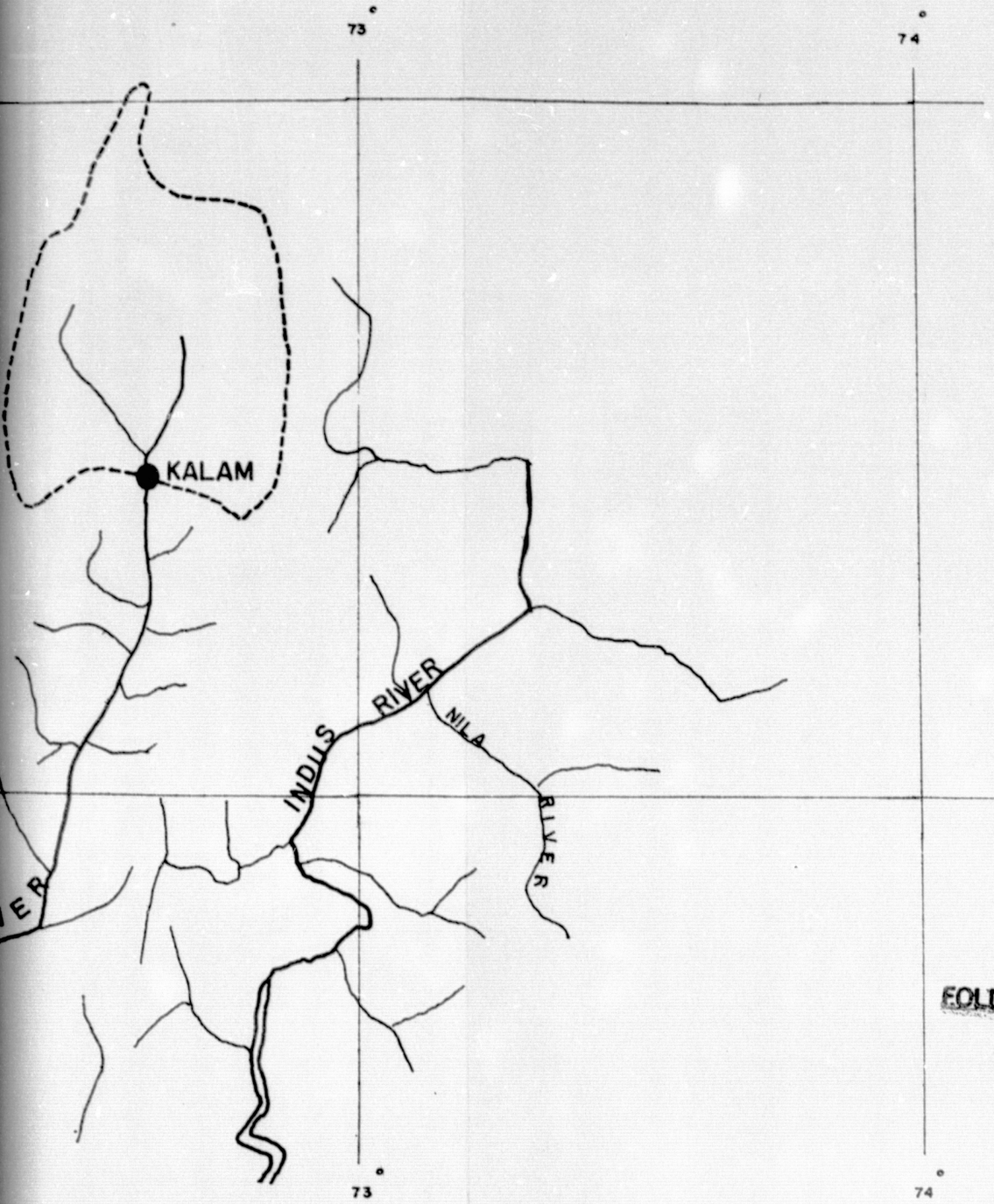
2 FOLDOUT FRAME

Fig 1

KEY MAP SHOWING THE PROJECT AREA



FOLDOUT FRAME



2

FOLDOUT FRAME

Fig. 2 SWAT RIVER NEAR KALAM

AREA = 780 Sq: Miles

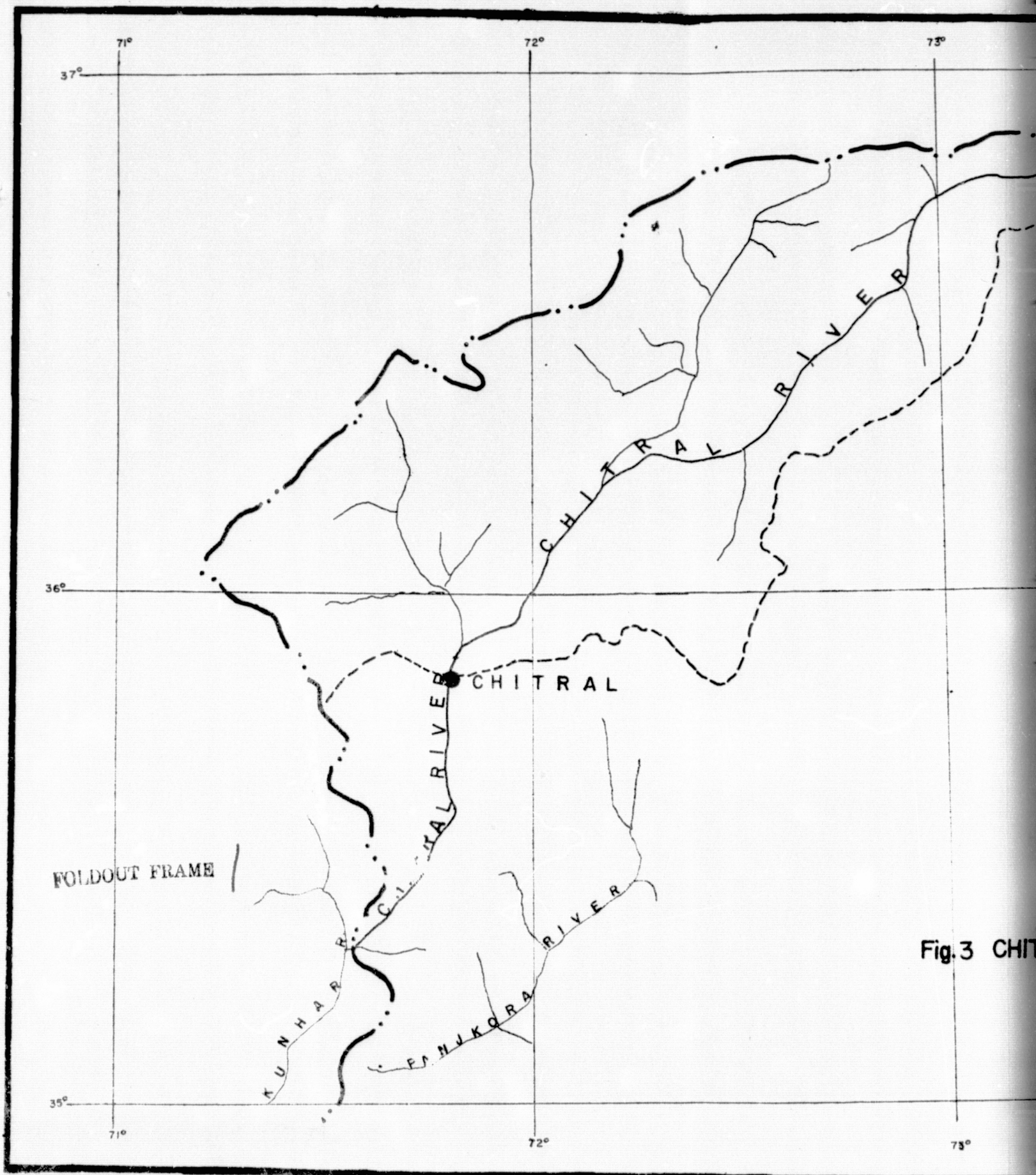
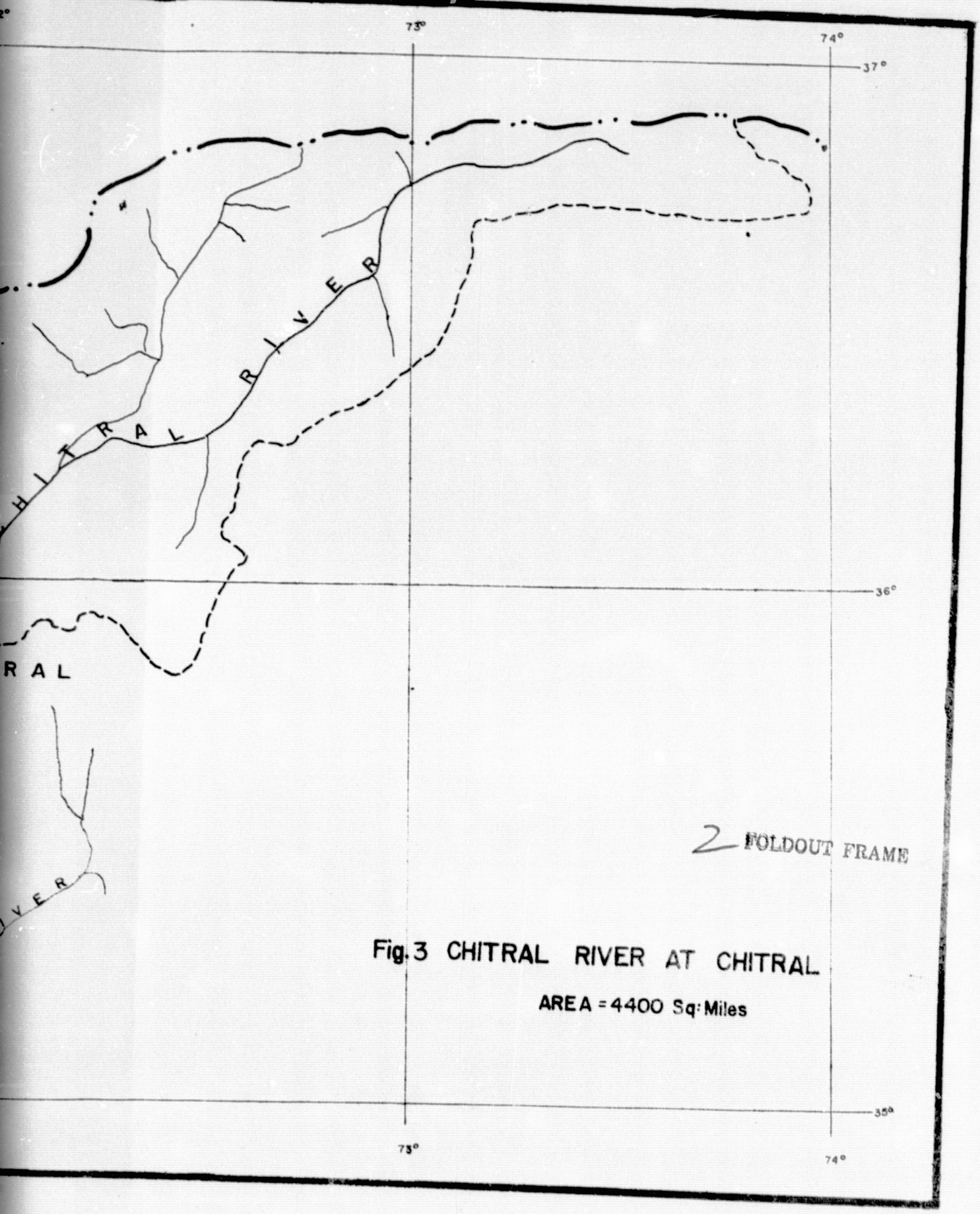

71°
72°
73°
37°
36°
35°
CHITRAL RIVER
CHITRAL
KUNHAR RIVER
PANJKORA RIVER
FOLDOUT FRAME

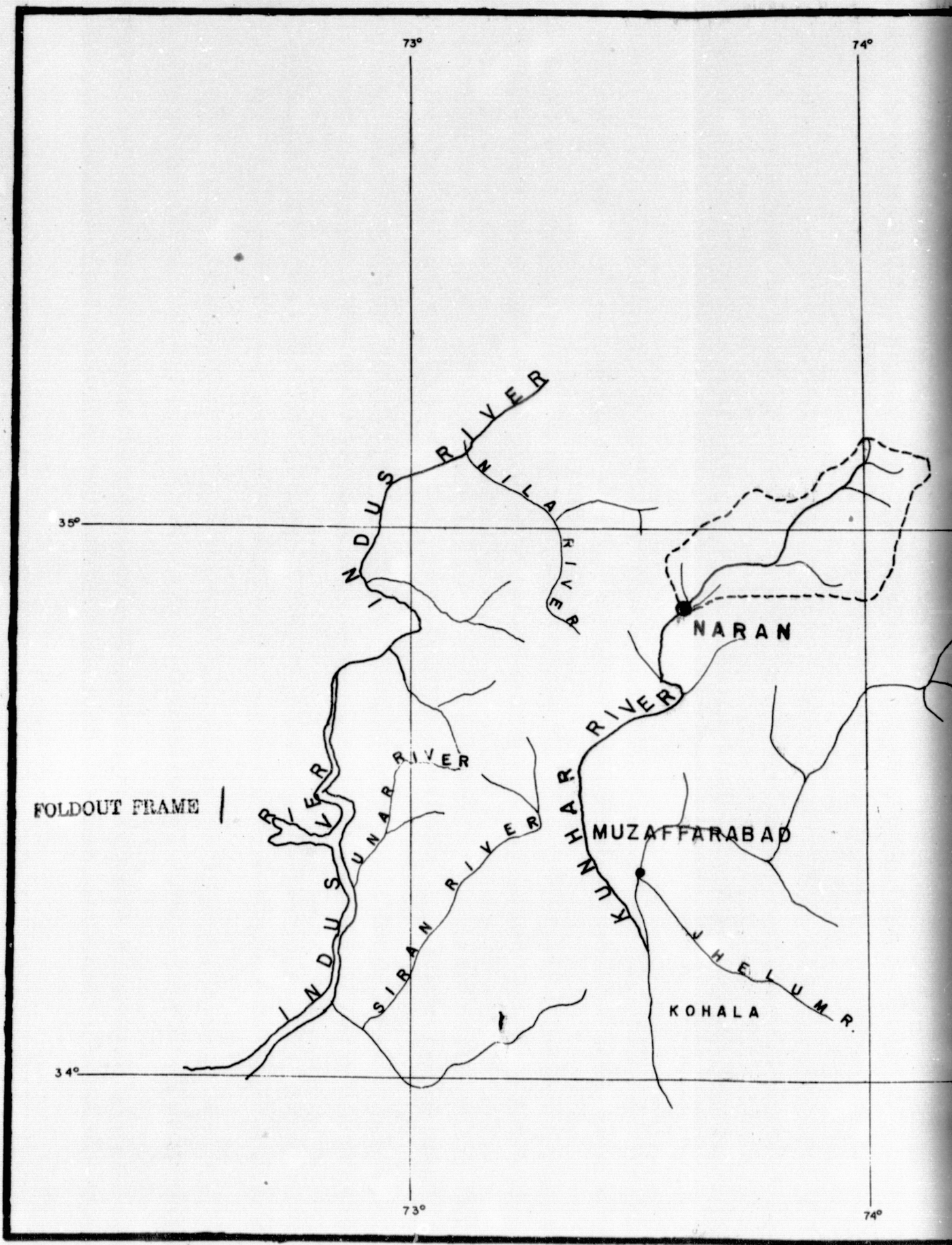
Fig. 3 CHIT



2 FOLDOUT FRAME

Fig. 3 CHITRAL RIVER AT CHITRAL

AREA = 4400 Sq: Miles


73°
74°
35°
34°
INDUS RIVER
NILA RIVER
NARAN
KUNHAR RIVER
MUZAFFARABAD
JHELUM R.
KOHALA
SIRAN RIVER
UNAR RIVER
INDUS RIVER
FOLDOUT FRAME

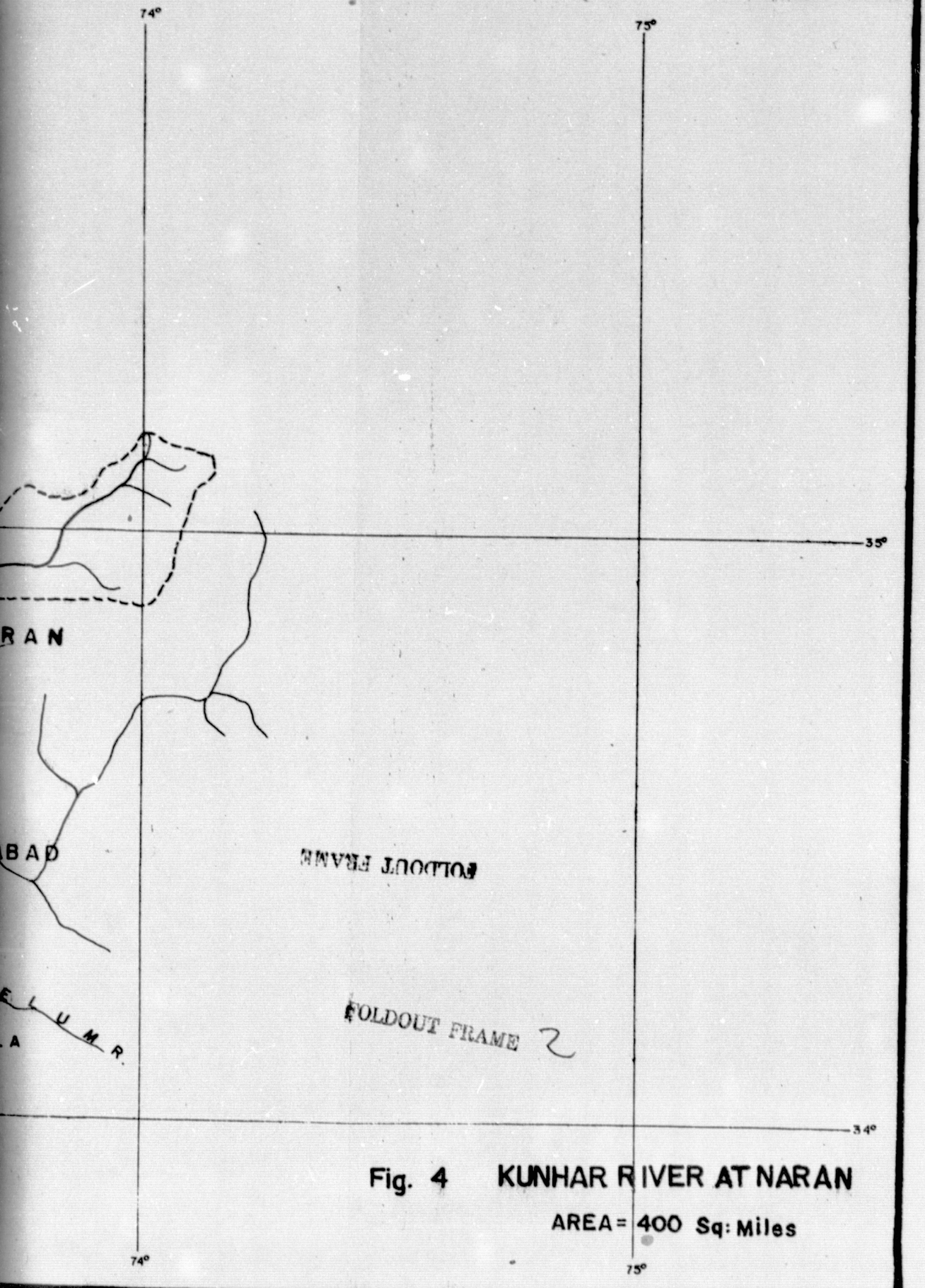
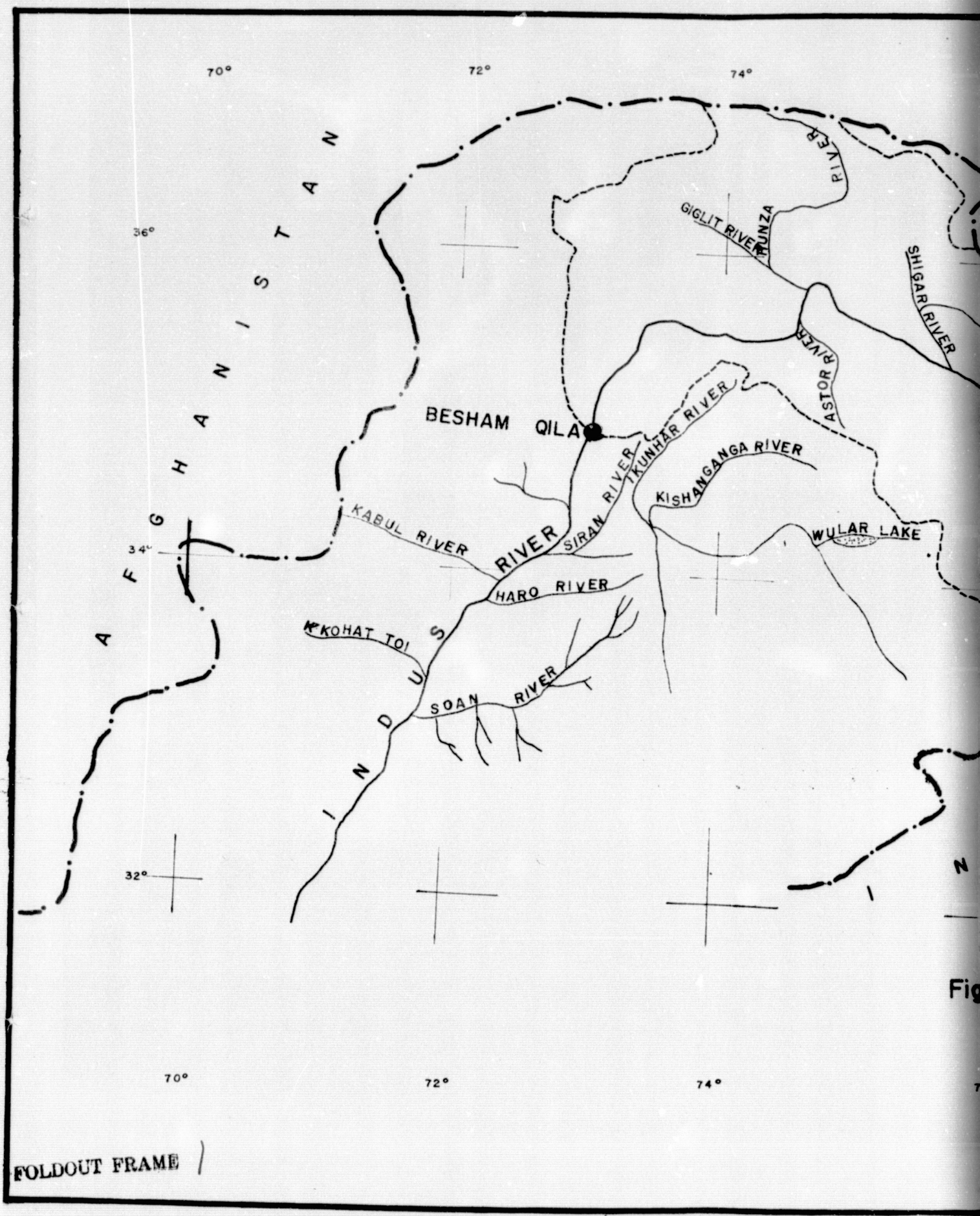


Fig. 4 KUNHAR RIVER AT NARAN

AREA = 400 Sq: Miles



FOLDOUT FRAME 1

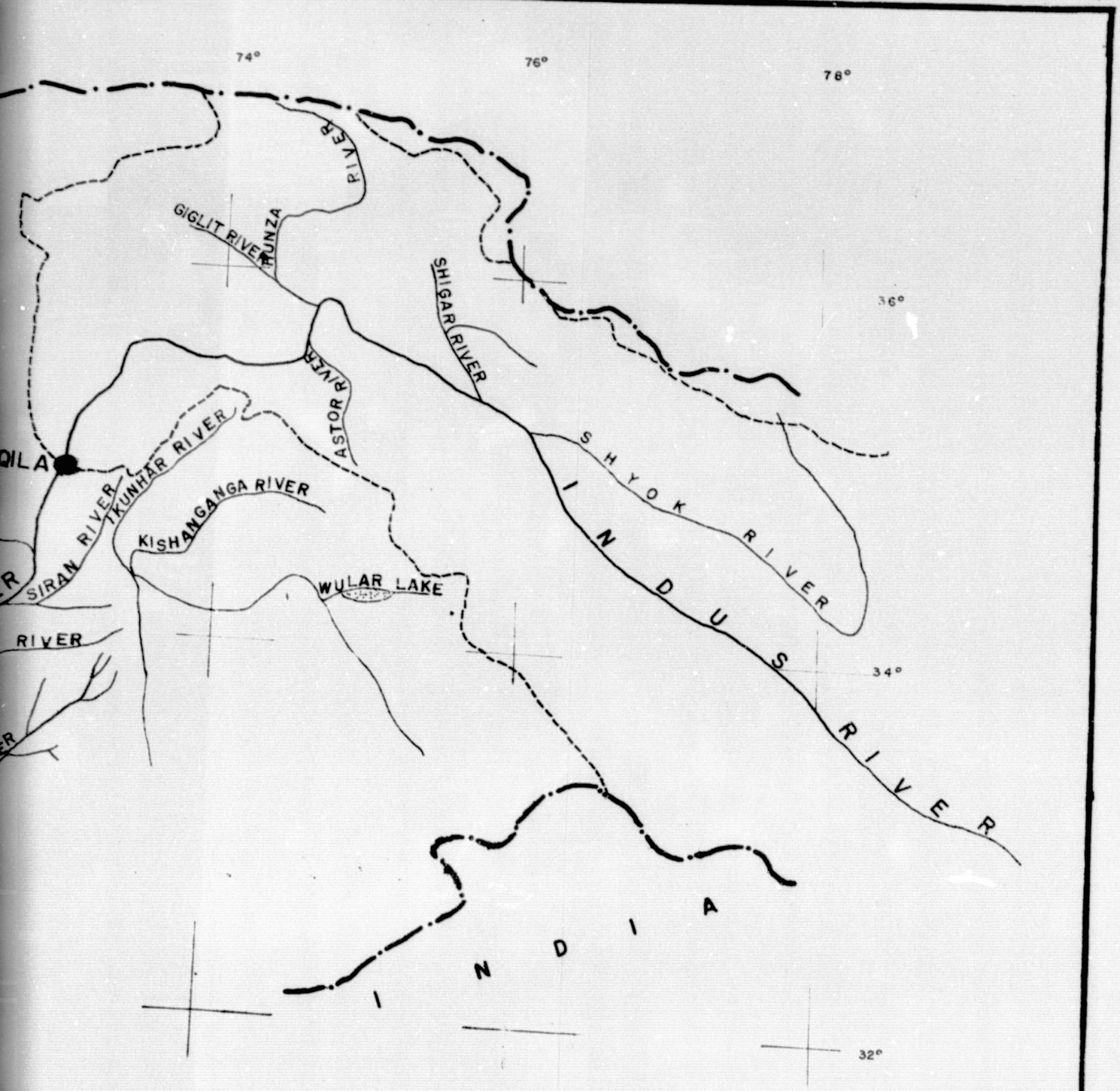


Fig. 5 INDUS RIVER AT BESHAM QILA

AREA=62700 Sq: Miles

FOLDOUT FRAME 2

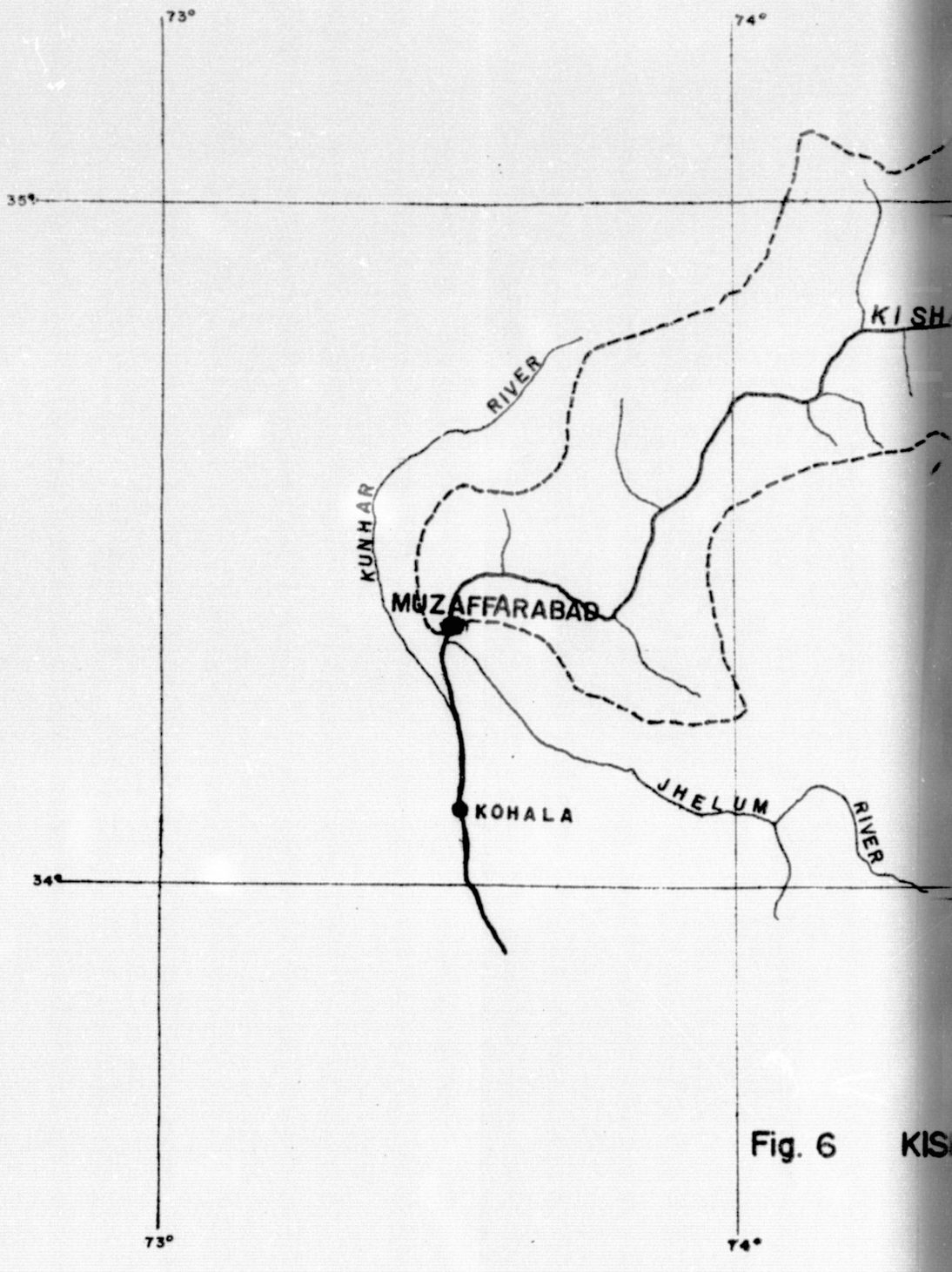


Fig. 6 KIS

FOLDOUT FRAME 1

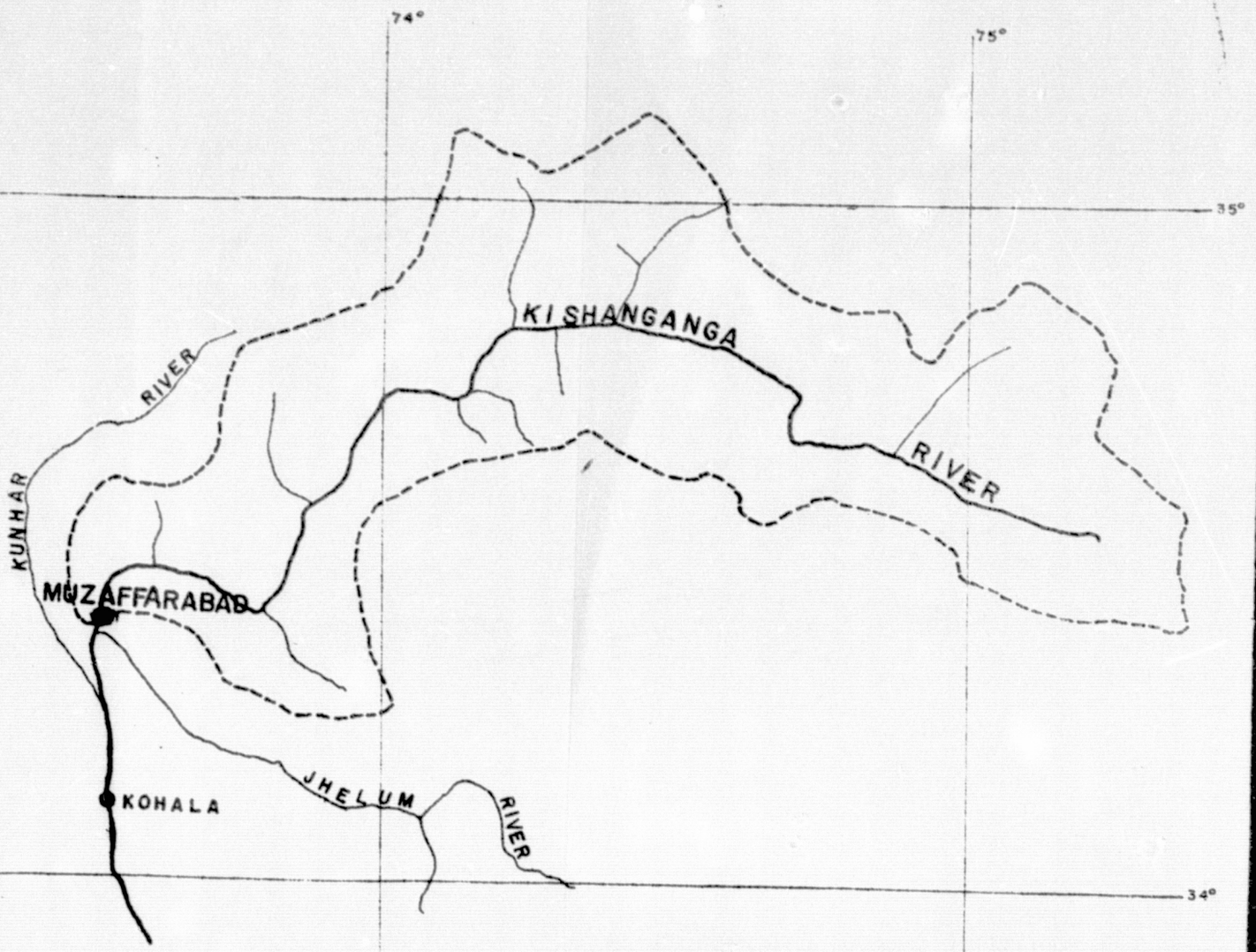
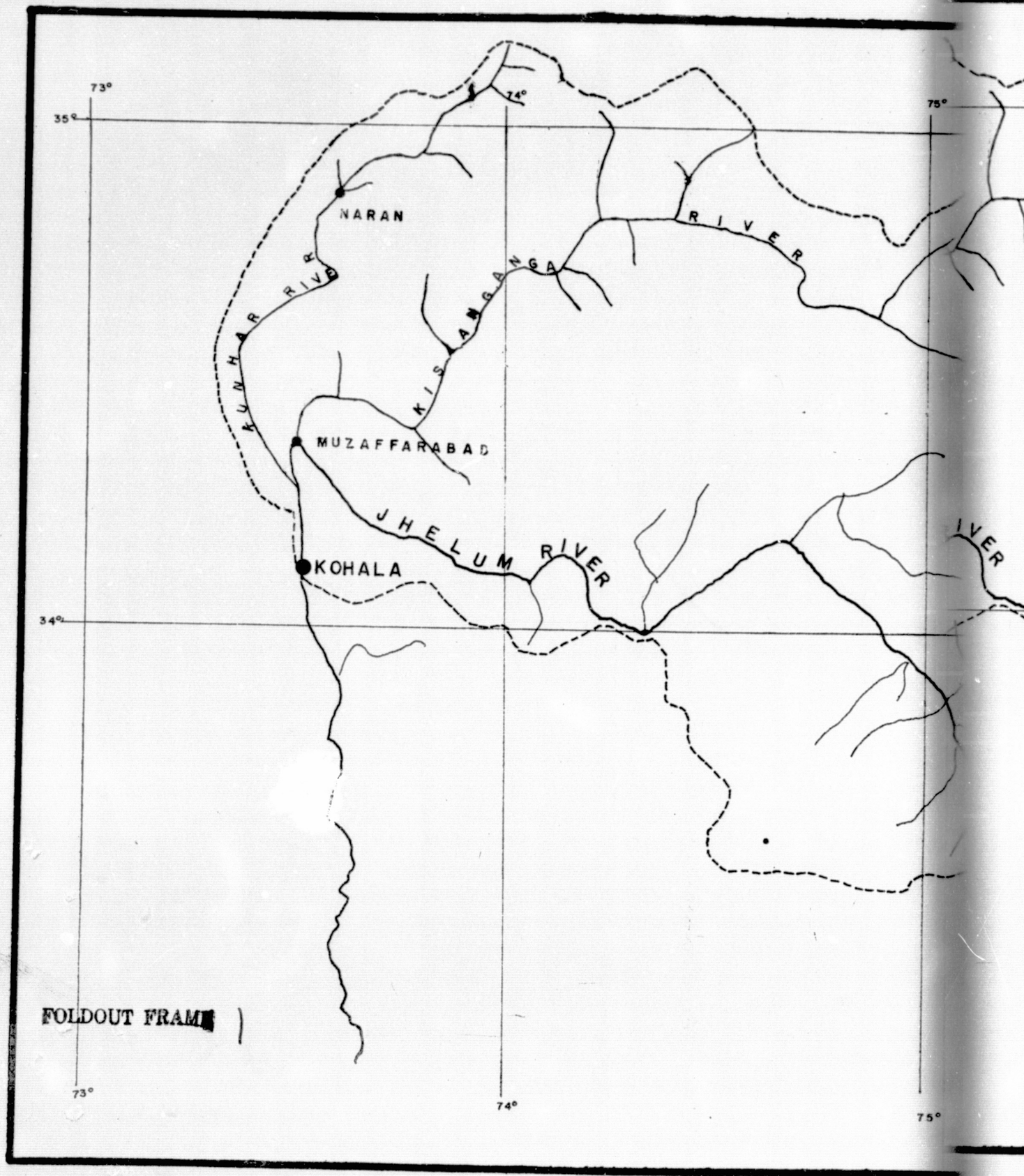
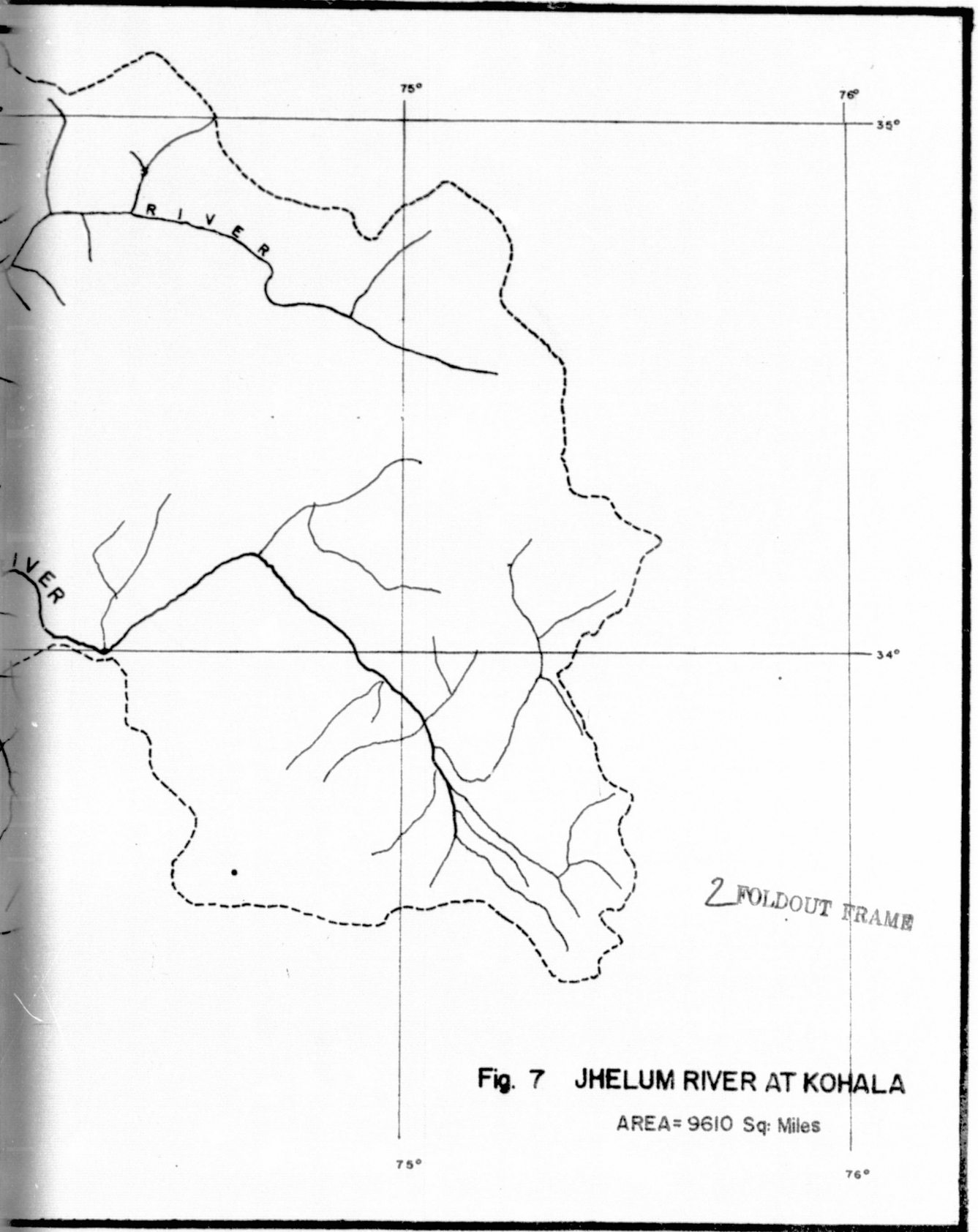


Fig. 6 KISHANGANGA RIVER AT MUZAFFARABAD

AREA = 2810 Sq: Miles

2 FOLDOUT FRAME


73°
74°
75°
35°
NARAN
KUNHAR RIVER
KISHANGANGA
RIVER
MUZAFFARABAD
JHELUM RIVER
KOHALA
34°
FOLDOUT FRAME
73°
74°
75°



2 FOLDOUT FRAME

Fig. 7 JHELUM RIVER AT KOHALA

AREA= 9610 Sq: Miles

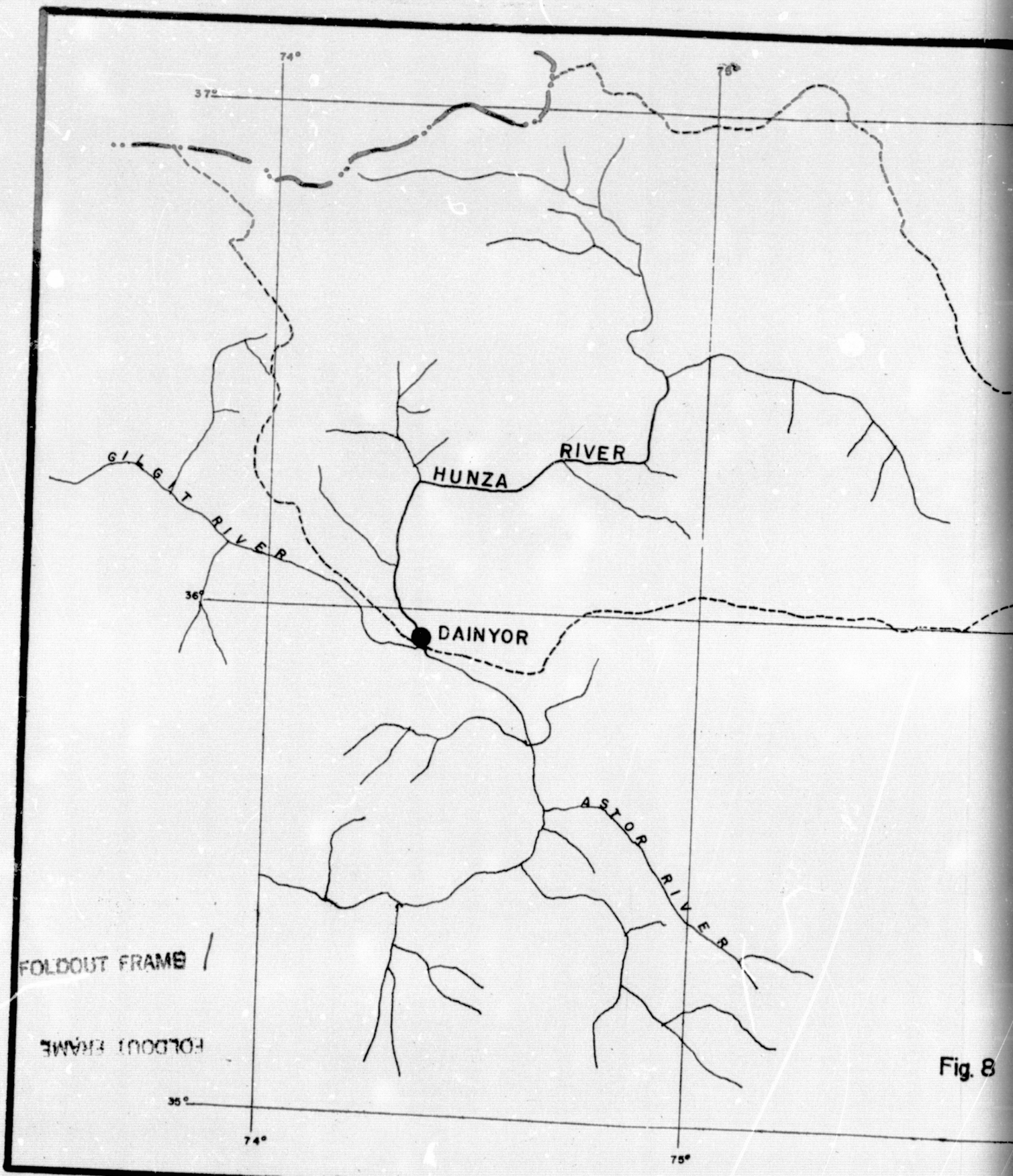
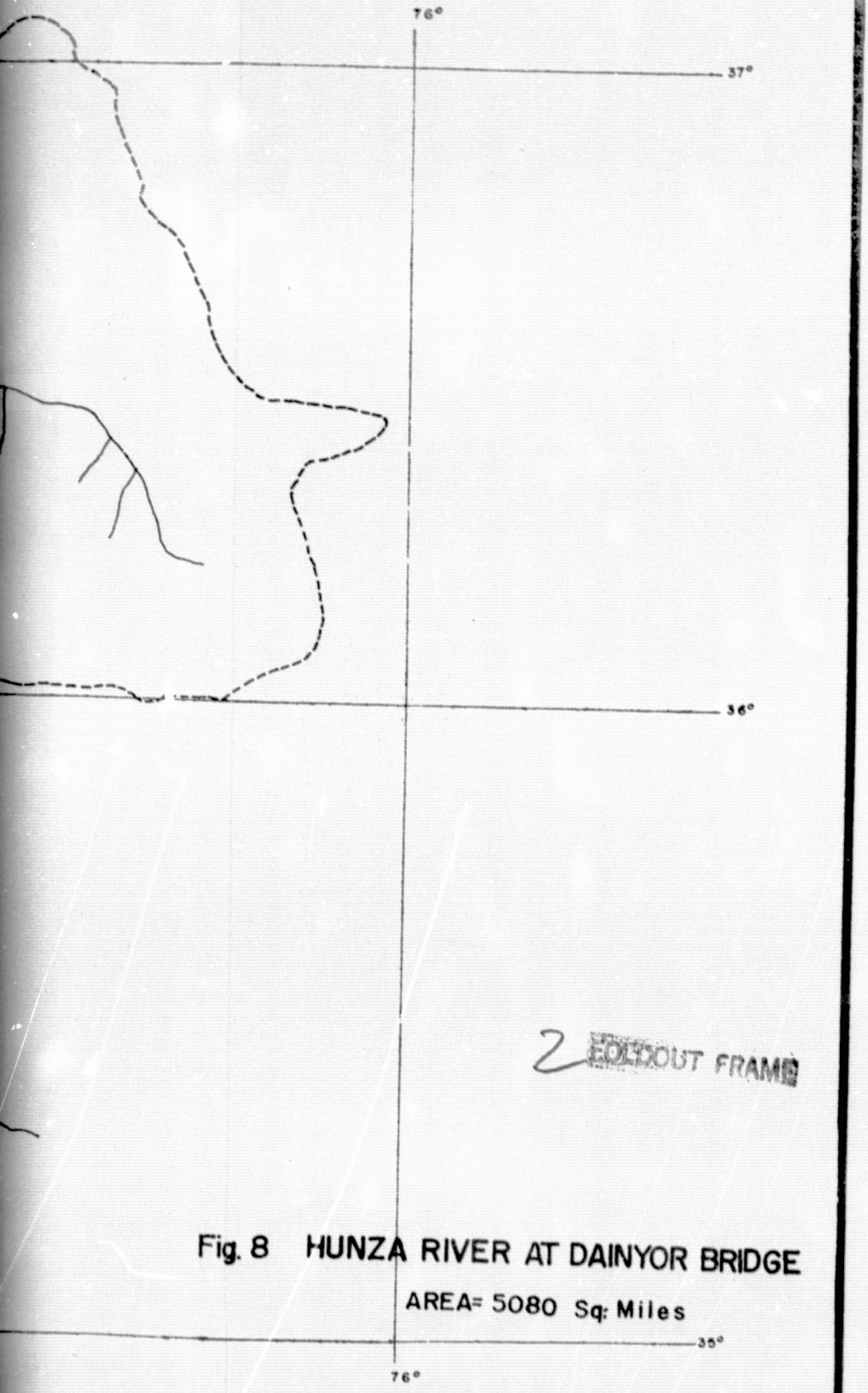

74°
75°
37°
GILGIT RIVER
HUNZA
RIVER
36°
DAINYOR
ASTOR RIVER
FOLDOUT FRAME
35°
74°
75°

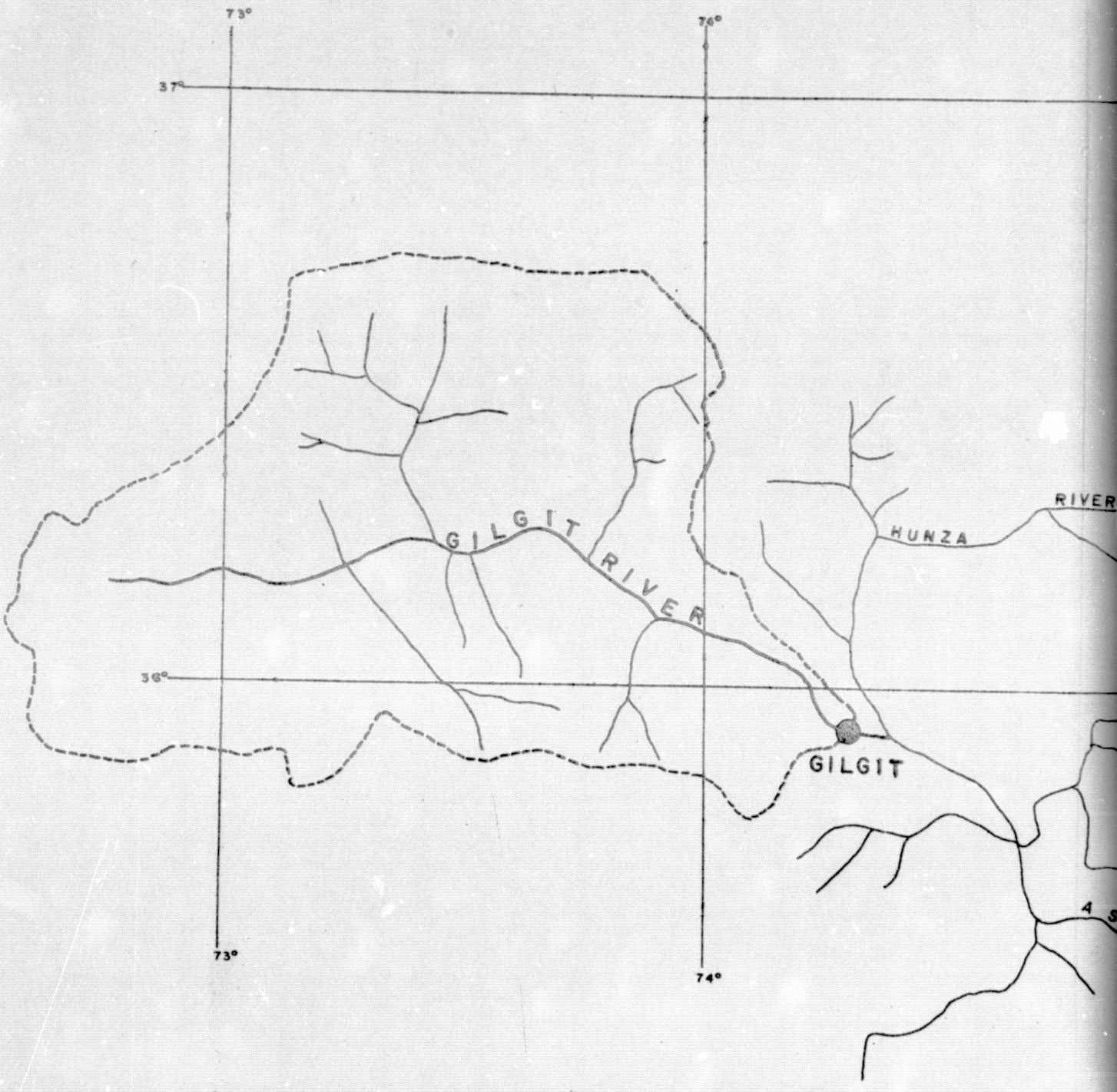
Fig. 8



2 FOLDOUT FRAME

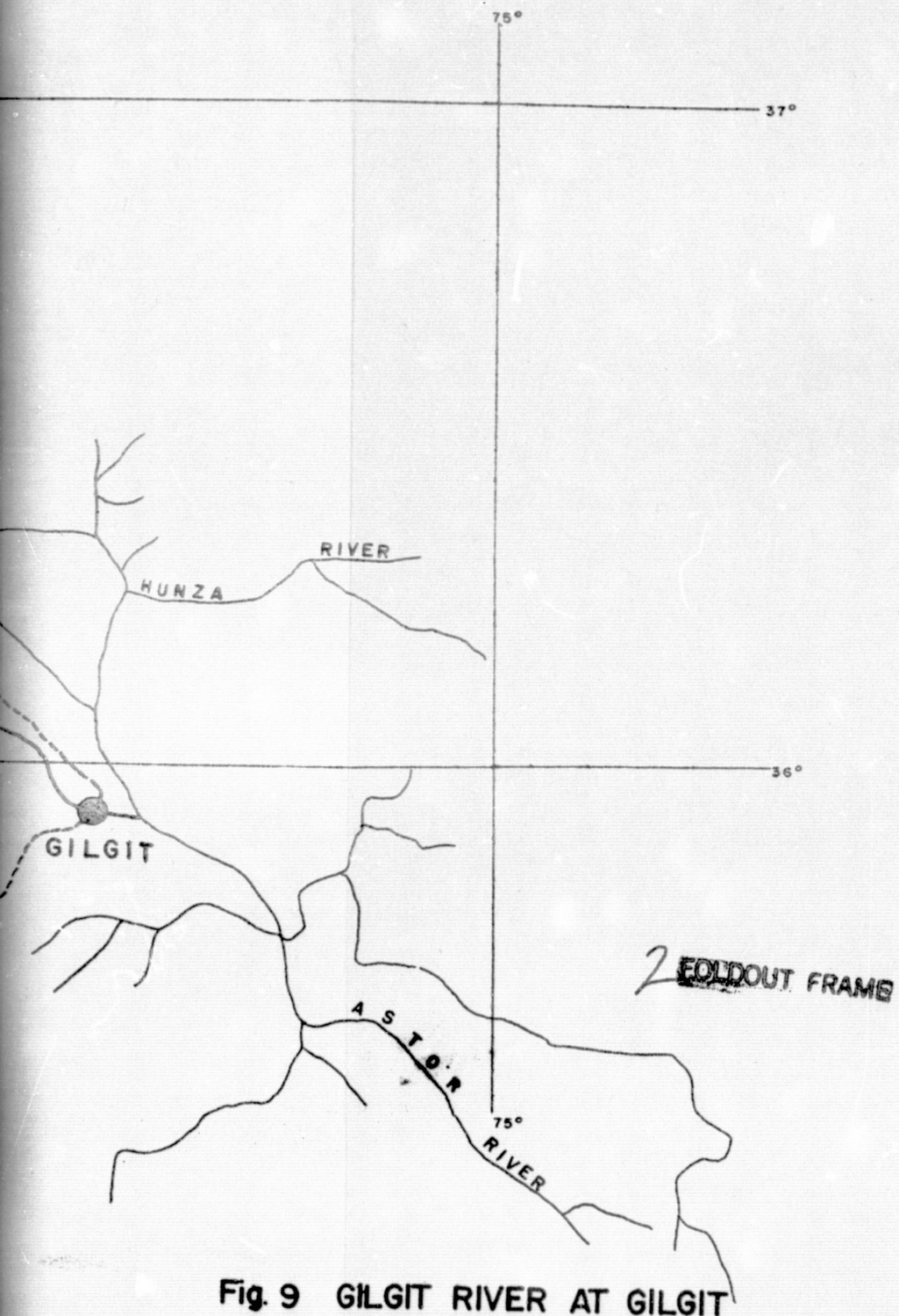
Fig. 8 HUNZA RIVER AT DAINYOR BRIDGE

AREA= 5080 Sq: Miles



FOLDOUT FRAME

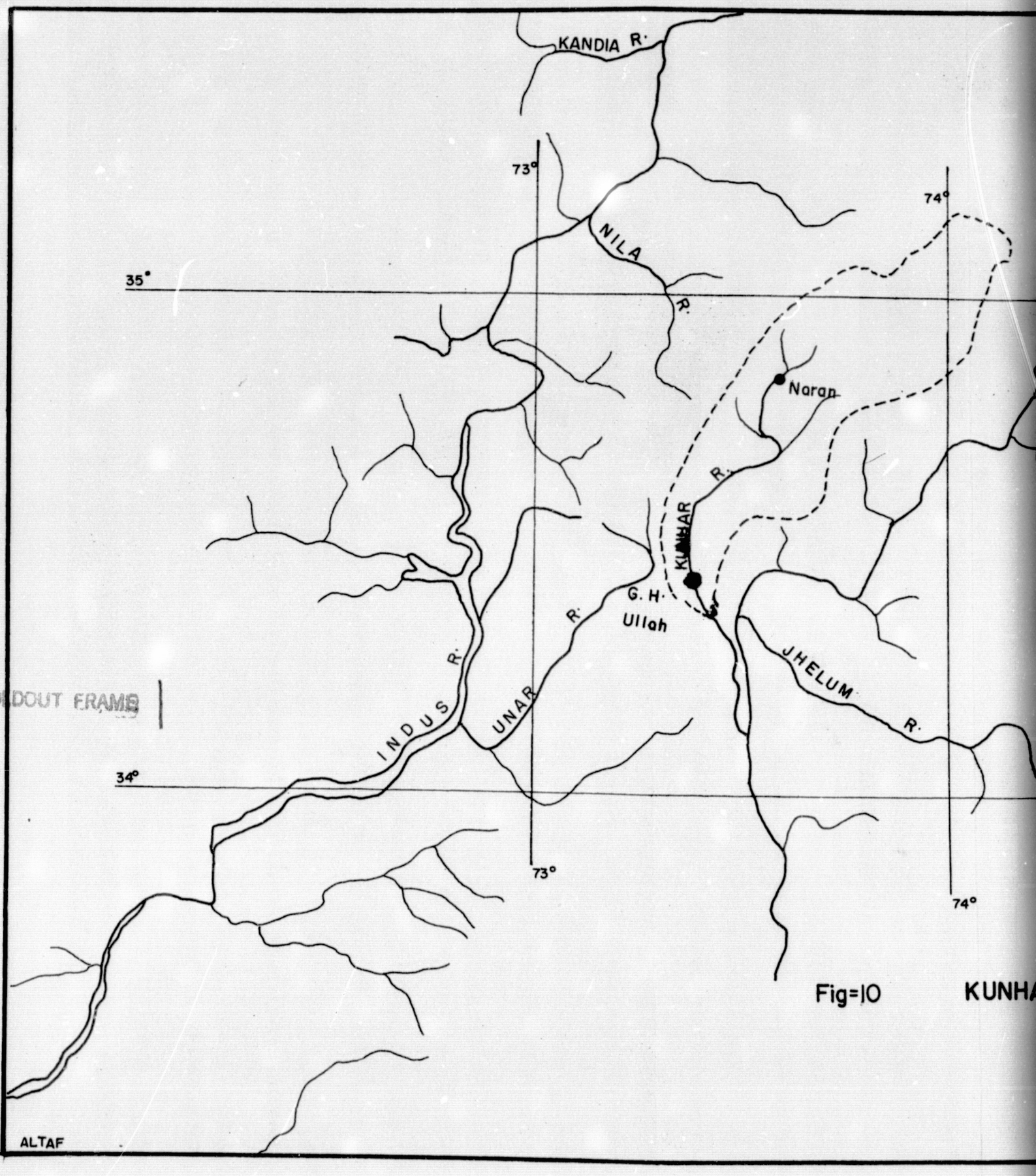
Fig. 9 GILG
A



2 FOLDOUT FRAME

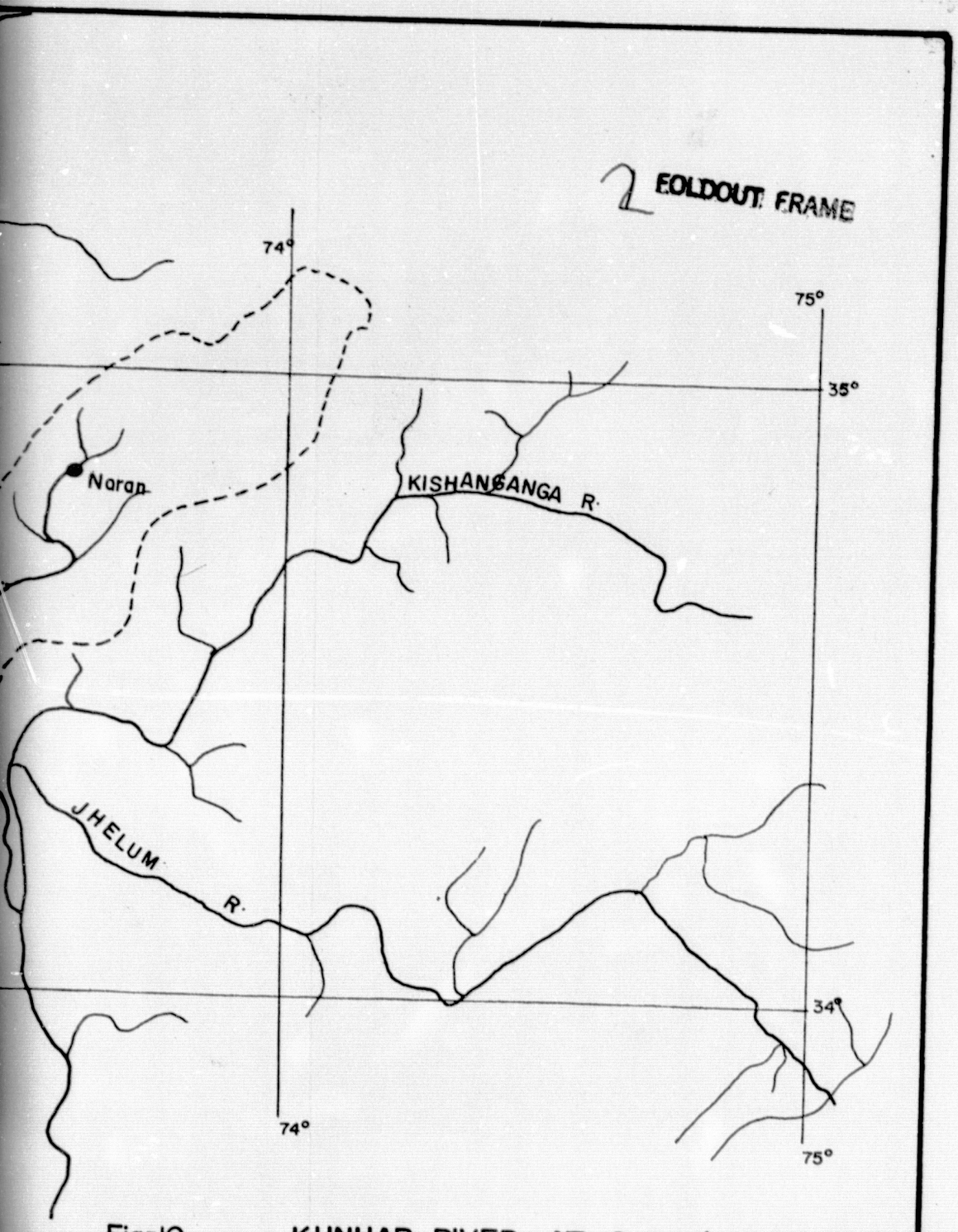
Fig. 9 GILGIT RIVER AT GILGIT

AREA= 4670 Sq: Miles



FOLDOUT FRAME

Fig=10 KUNHA



Fig=10 KUNHAR RIVER AT G.H. ULLAH

Area= 920 Sq Miles

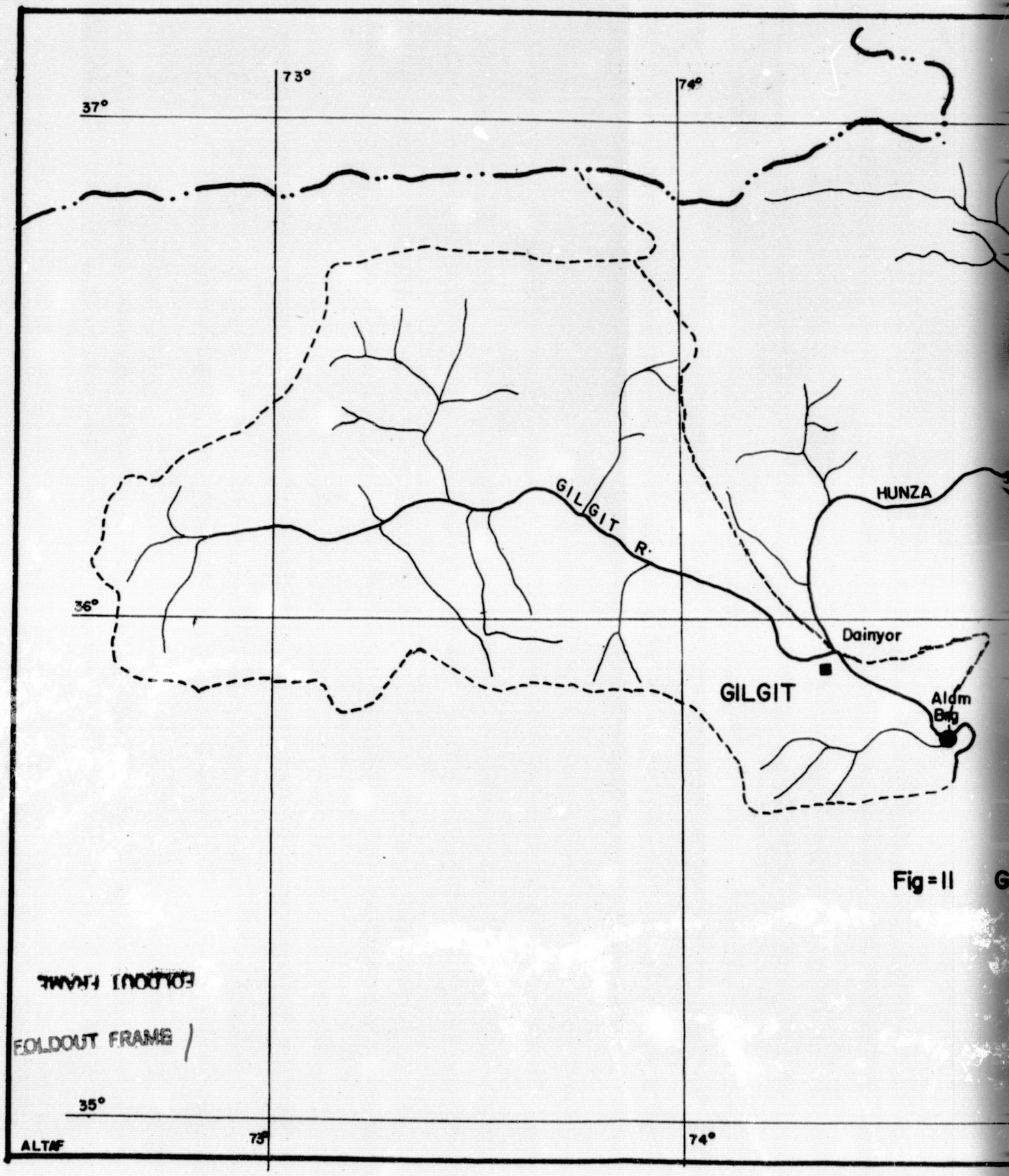


Fig = II G

FOLDOUT FRAME

FOLDOUT FRAME

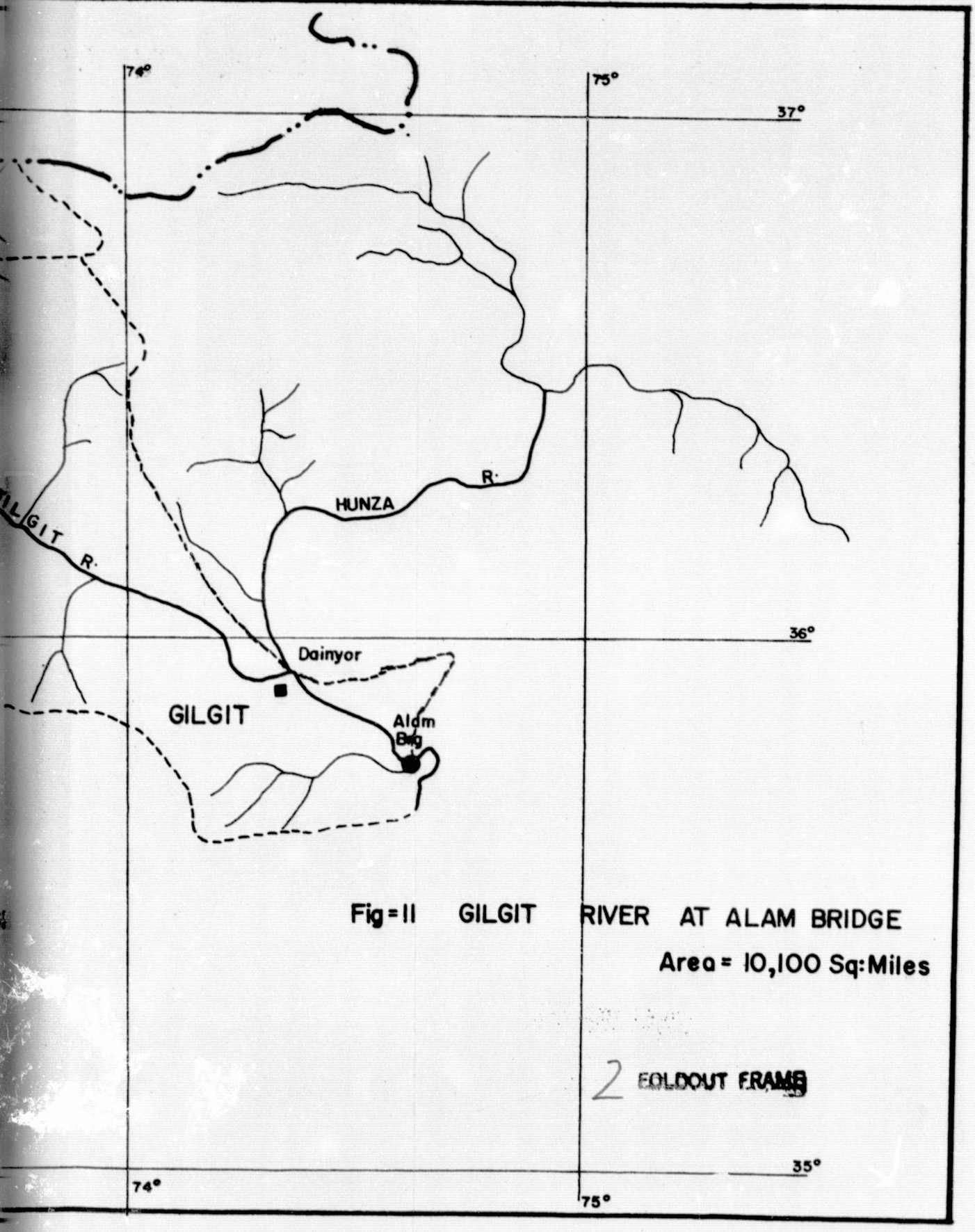
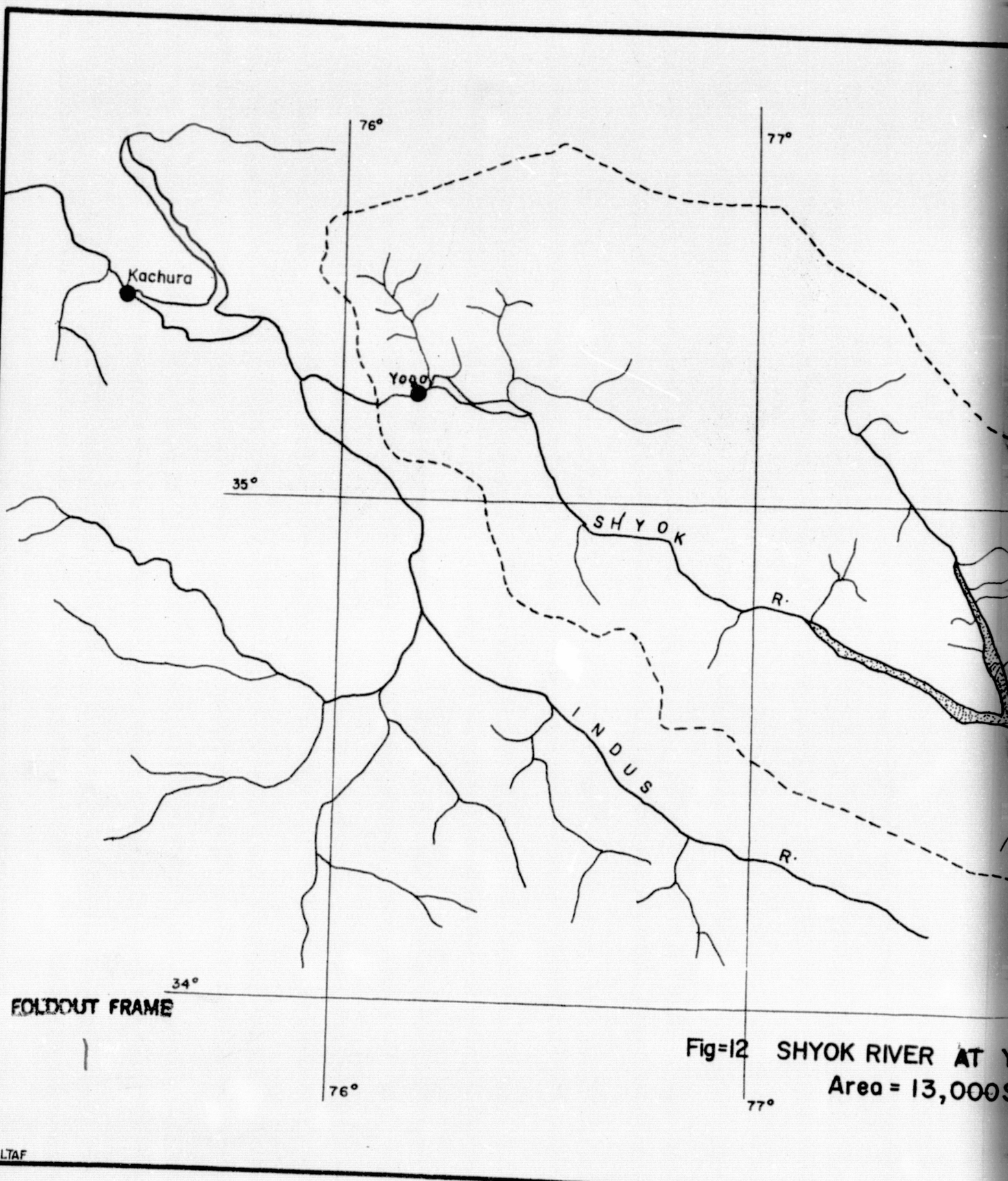


Fig = 11 GILGIT RIVER AT ALAM BRIDGE

Area = 10,100 Sq: Miles

2 FOLDOUT FRAME

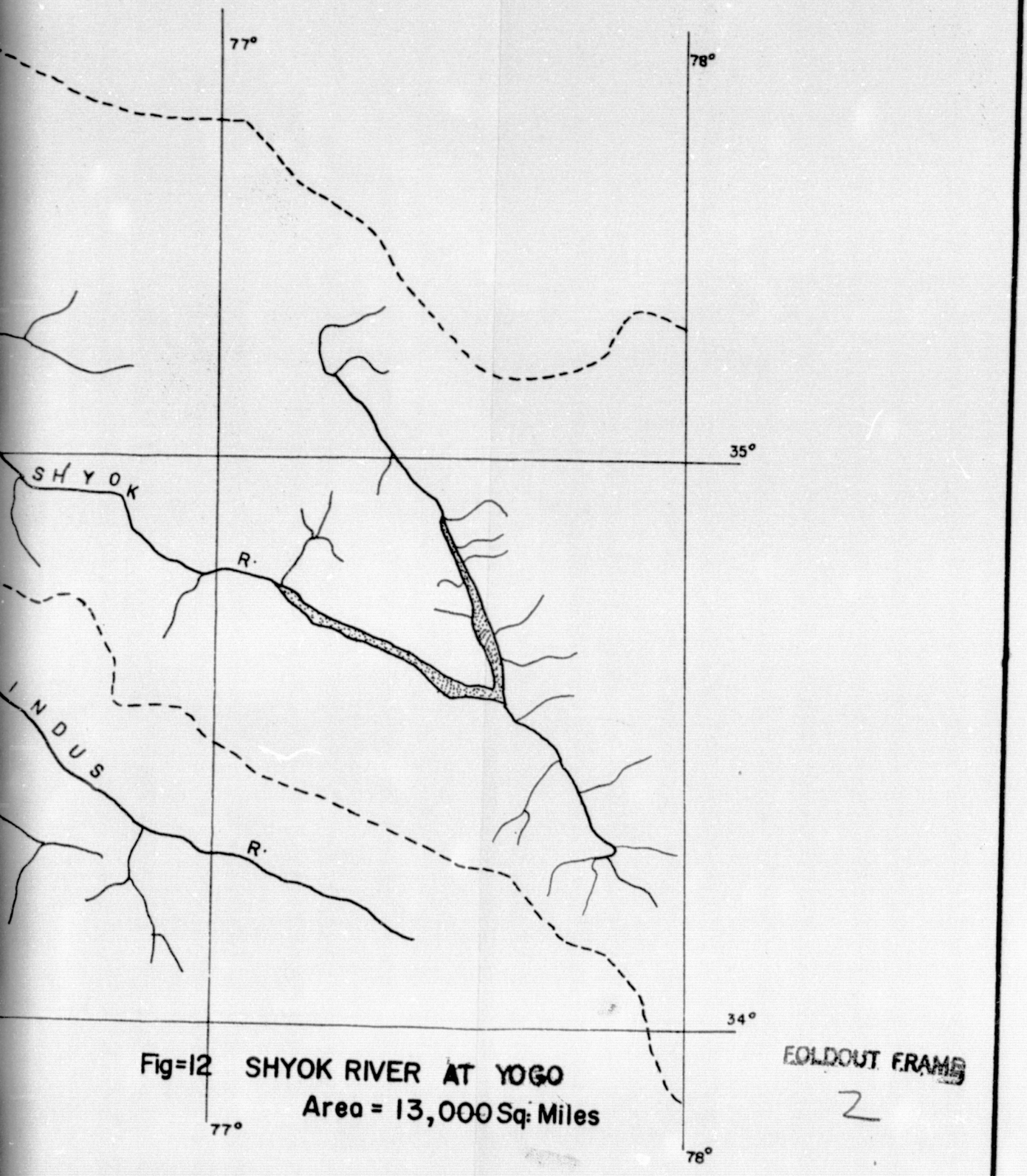


FOLDOUT FRAME

Fig=12 SHYOK RIVER AT Y

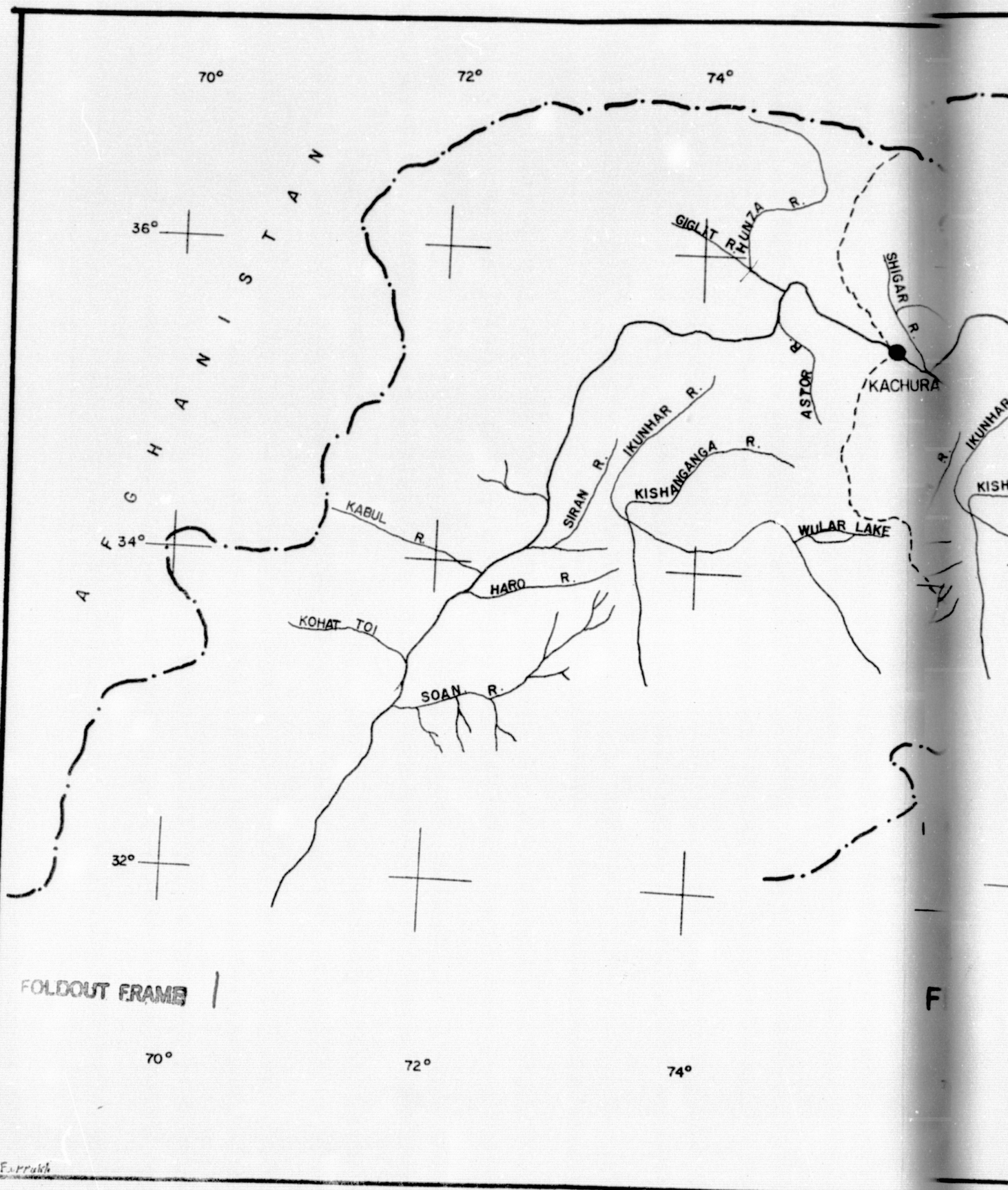
Area = 13,000

ALTAF



Fig=12 SHYOK RIVER AT YOGO
Area = 13,000 Sq: Miles

FOLDOUT FRAME
2


70°
72°
74°
36°
34°
32°
AFGHANISTAN
GILGIT R.
HUNZA R.
SHIGAR R.
KACHURA
ASTOR R.
IKUNHAR R.
KISHANGANGA R.
SIRAN R.
KABUL R.
HARO R.
KOHAT TOI
SOAN R.
WULAR LAKE
FOLDOUT FRAME
70°
72°
74°

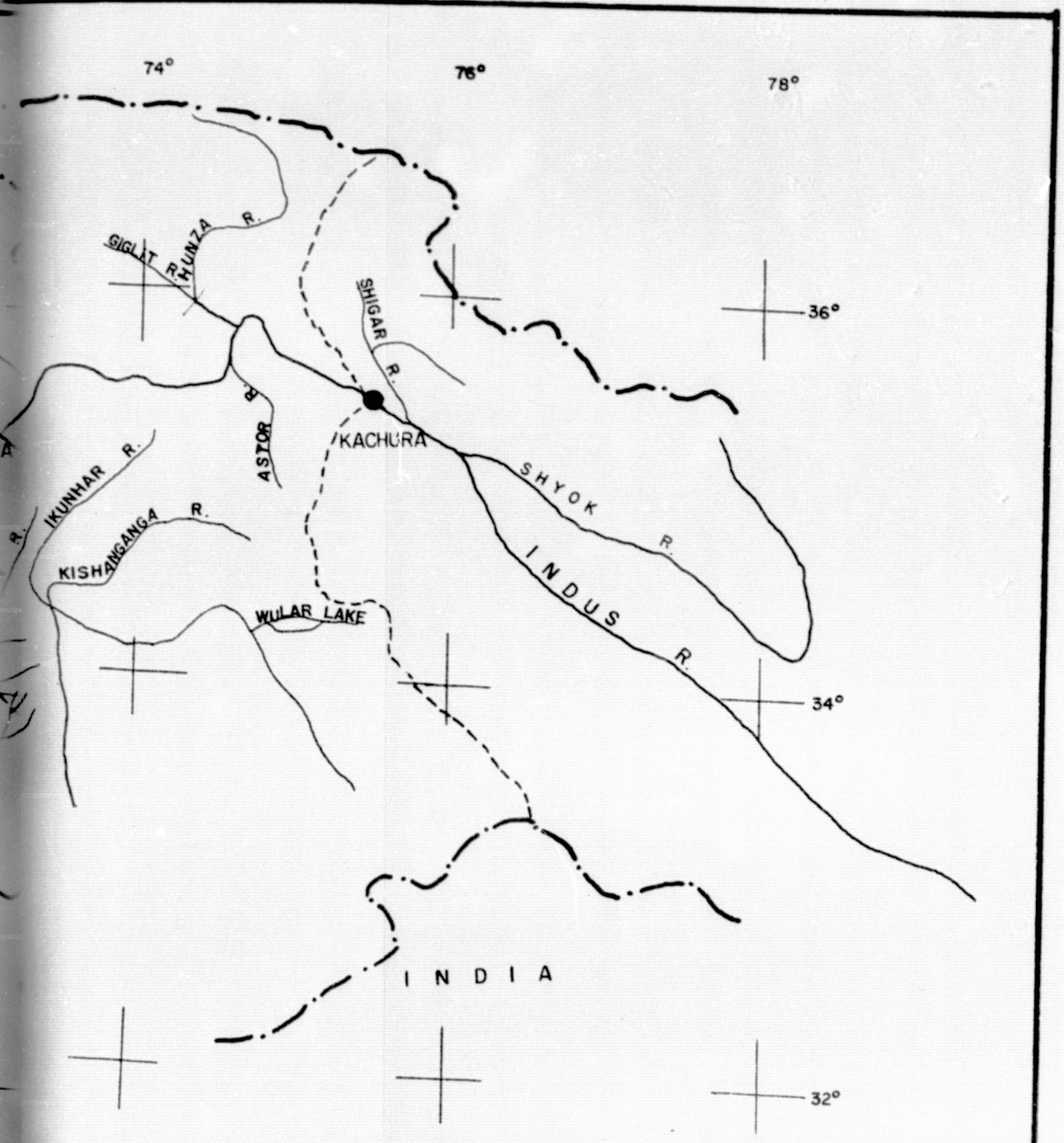
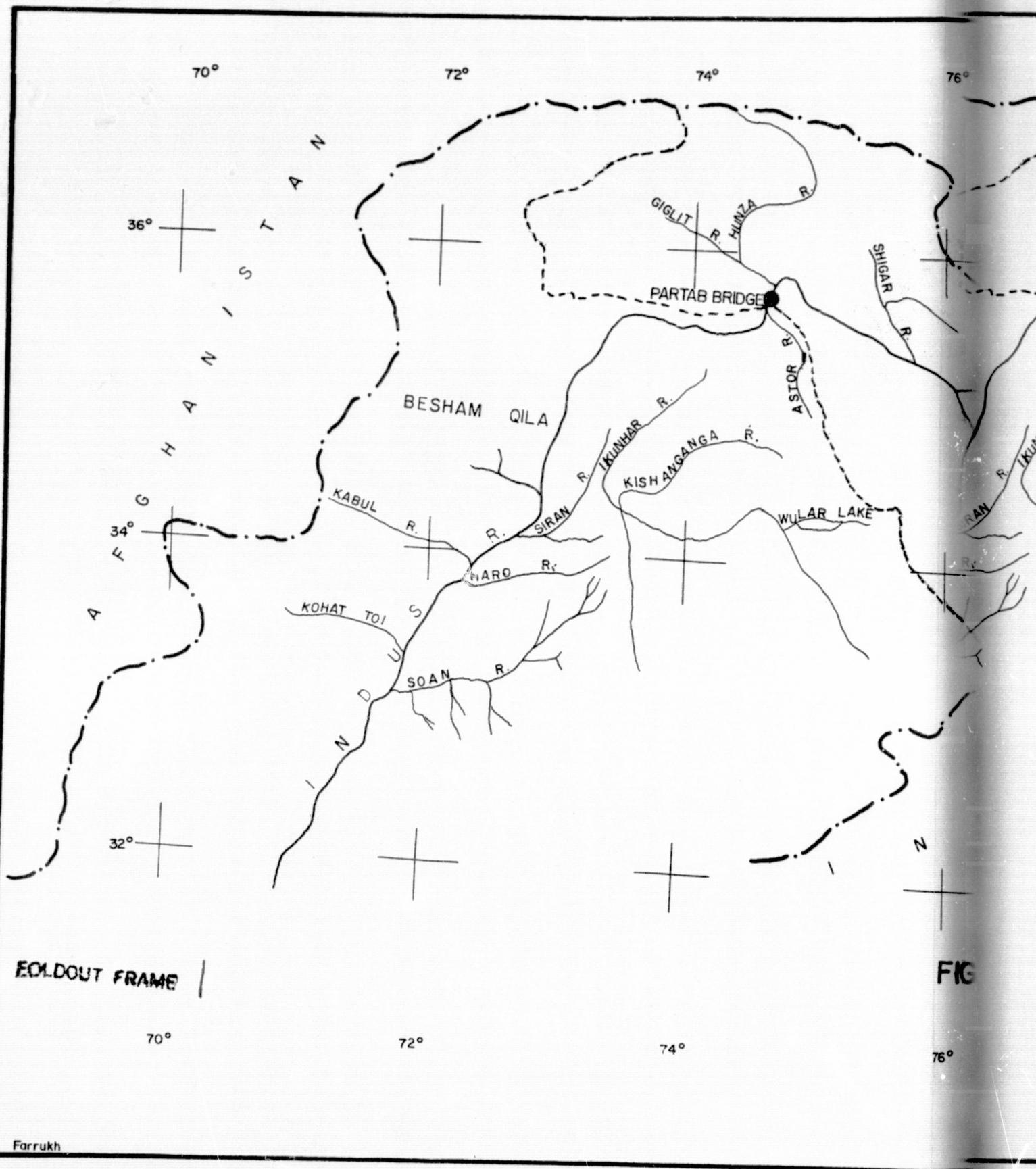


FIG 13 INDUS RIVER AT KACHURA

Area =43500 sq miles

2 FOLDOUT FRAME


70°
72°
74°
76°
36°
34°
32°
AFGHANISTAN
BESHAM QILA
PARTAB BRIDGE
GIGLIT R.
HUNZA R.
SHIGAR R.
ASTOR R.
KISHANGANGA R.
KUNHAR R.
SIRAN R.
KABUL R.
HARO R.
KOHAT TOI
SOAN R.
INDUS
WULAR LAKE
FOLDOUT FRAME
Farrukh

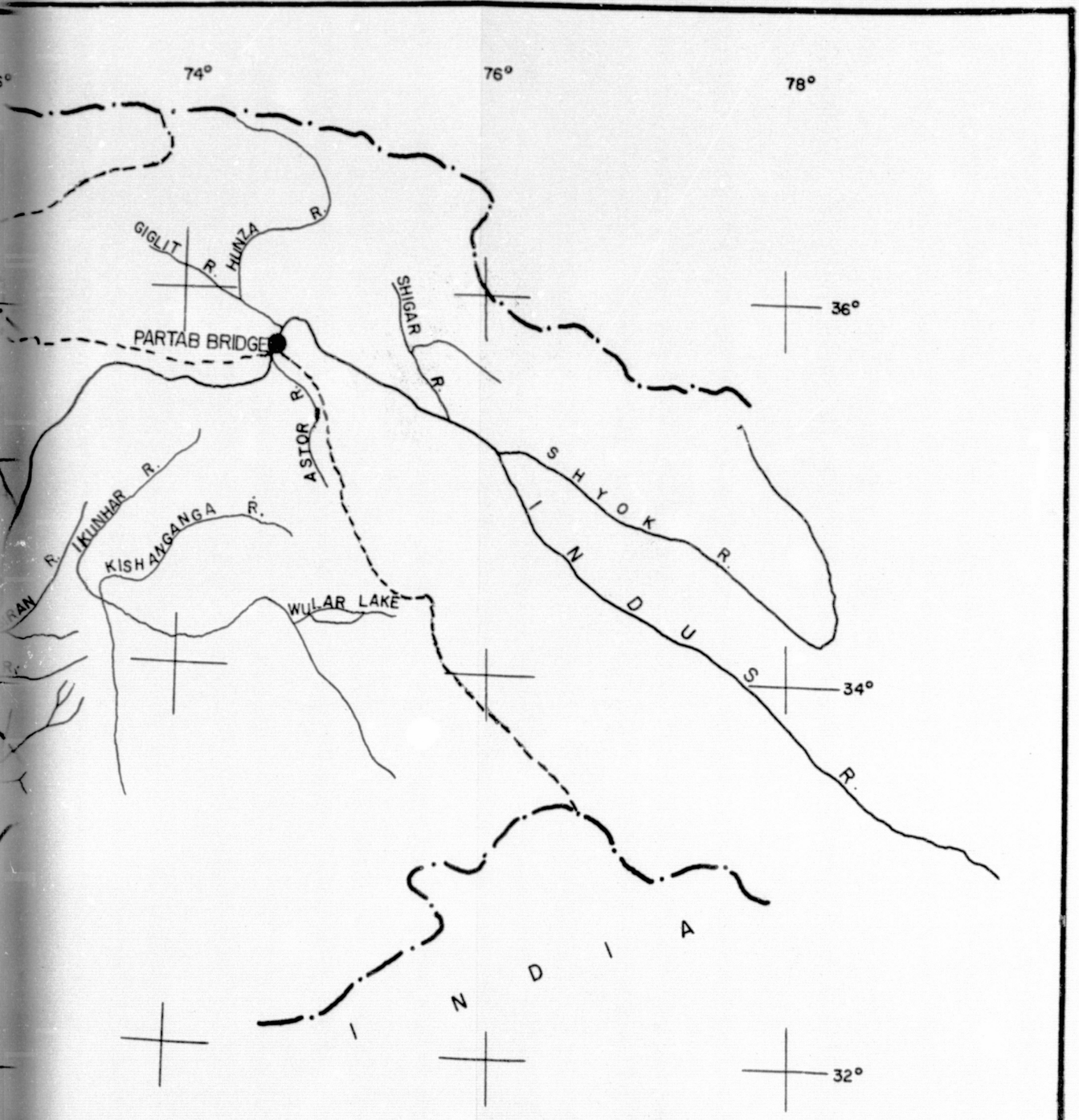
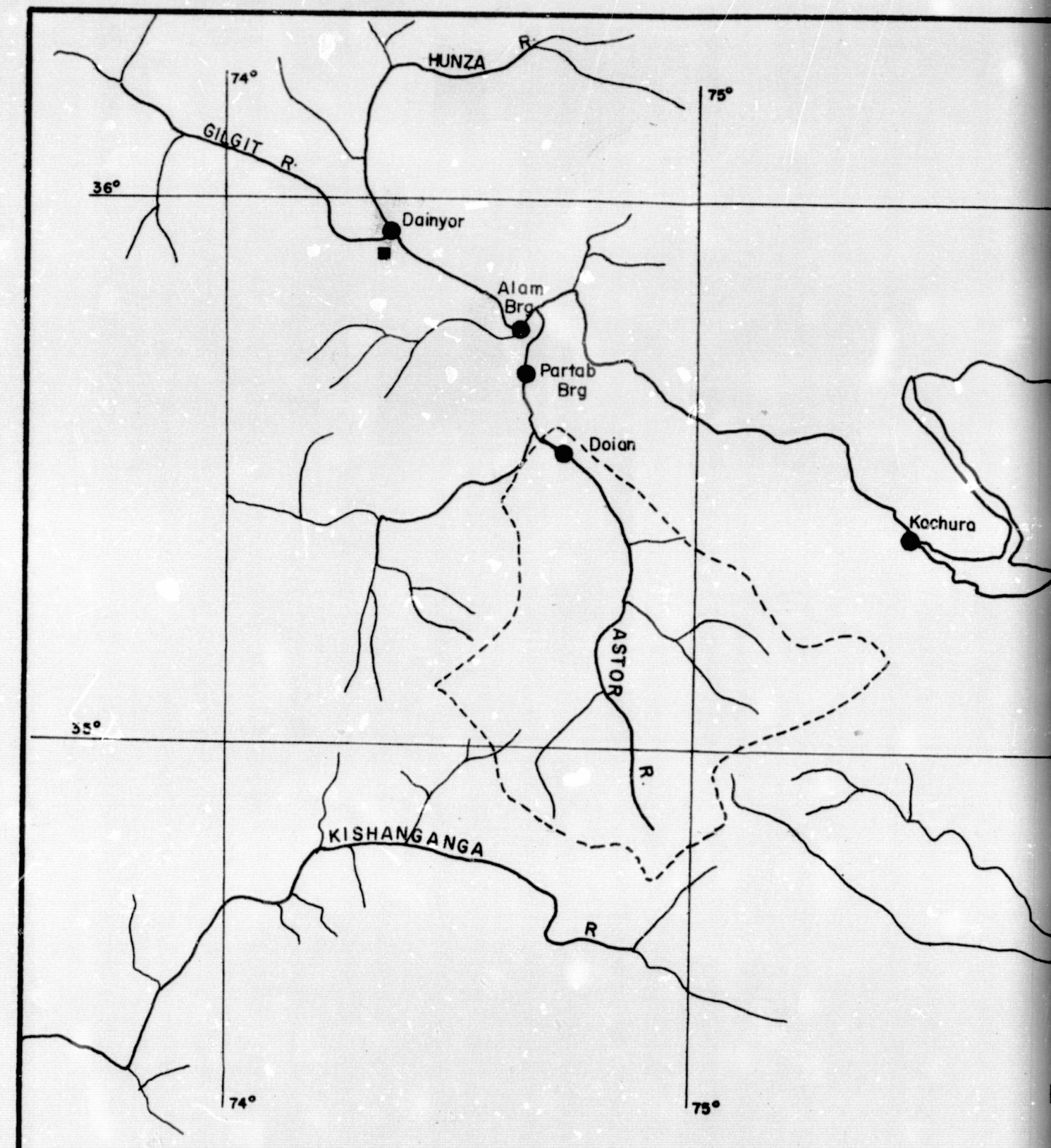


FIG 14 INDUS RIVER AT PARTAB BRIDGE AREA = 55,100 sqmile

2 FOLDOUT FRAME



FOLDOUT FRAME 1

ALTAF.

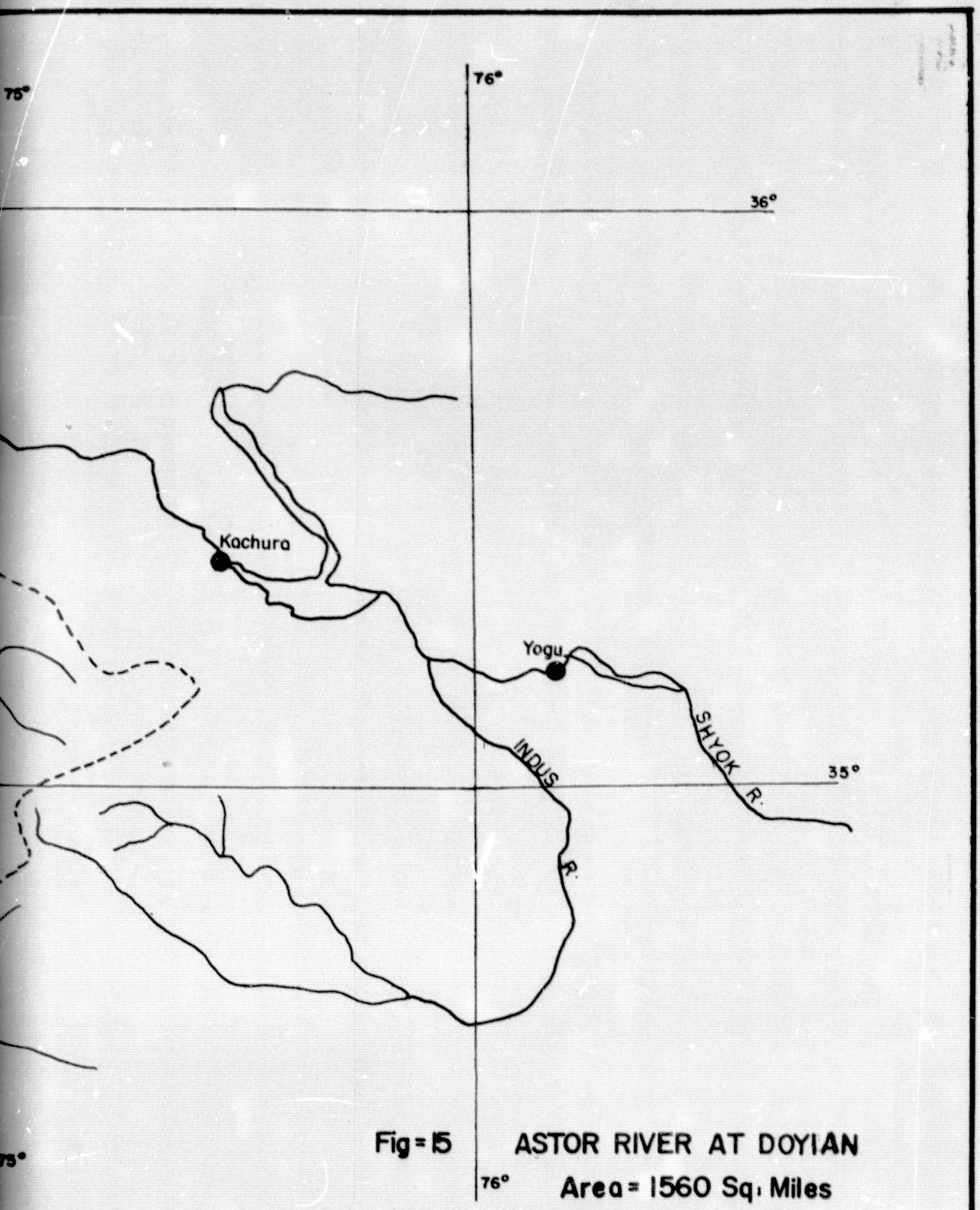
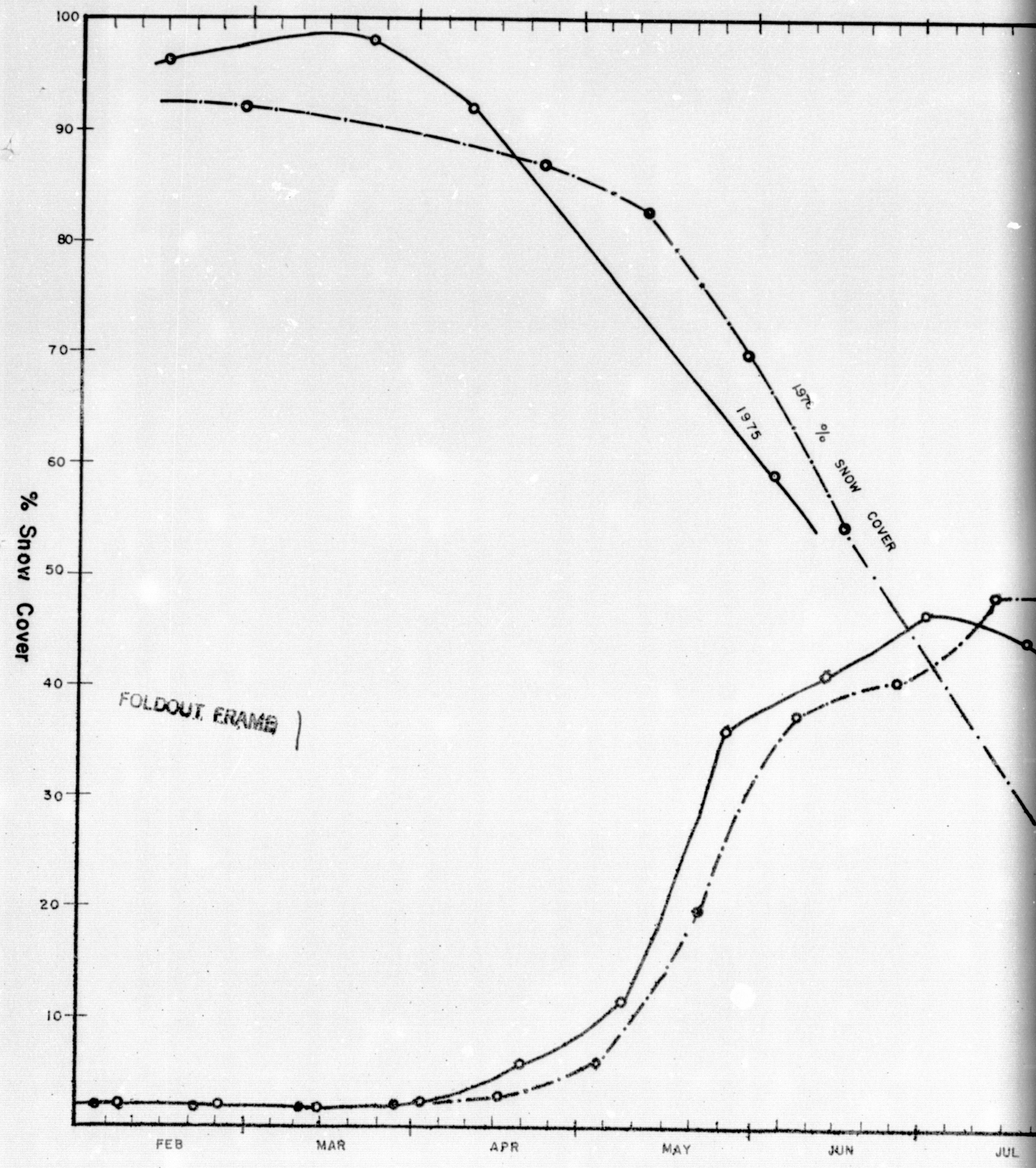
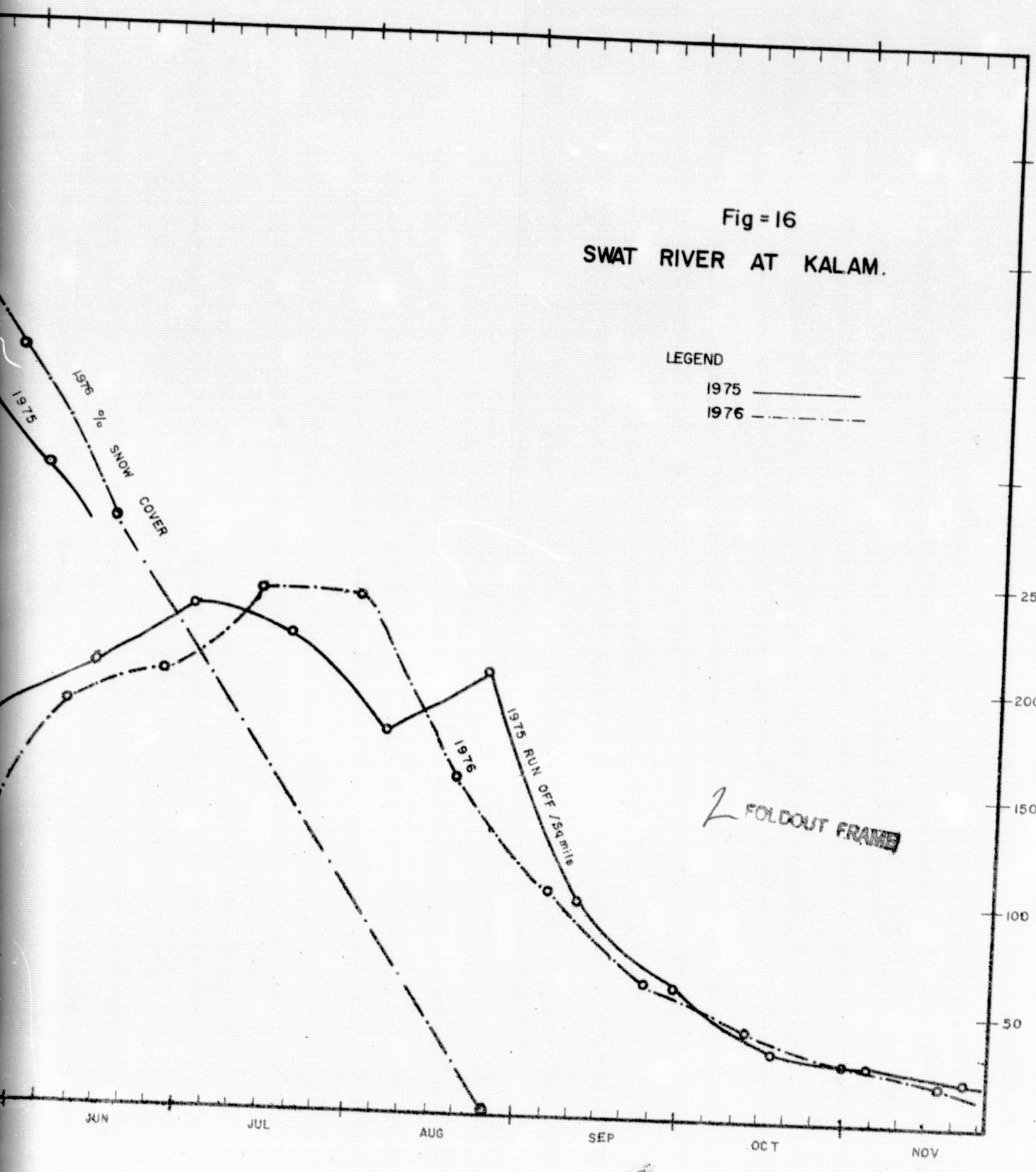


Fig = 15 ASTOR RIVER AT DOYIAN

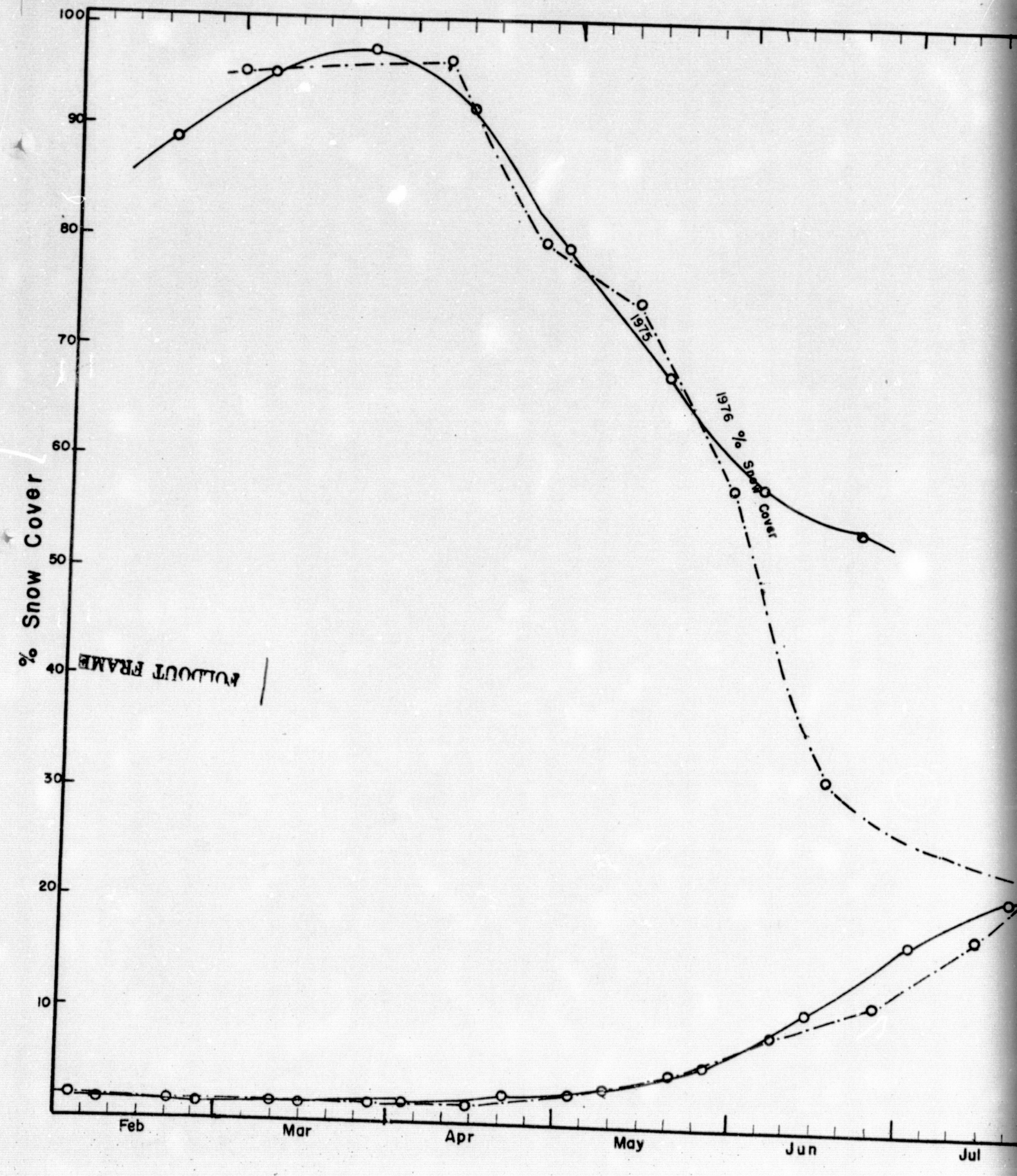
Area = 1560 Sq. Miles

2 FOLDOUT FRAME


100
90
80
70
60
50
40
30
20
10
% Snow Cover
1975
197? % SNOW COVER
FOLDOUT FRAME
FEB
MAR
APR
MAY
JUN
JUL



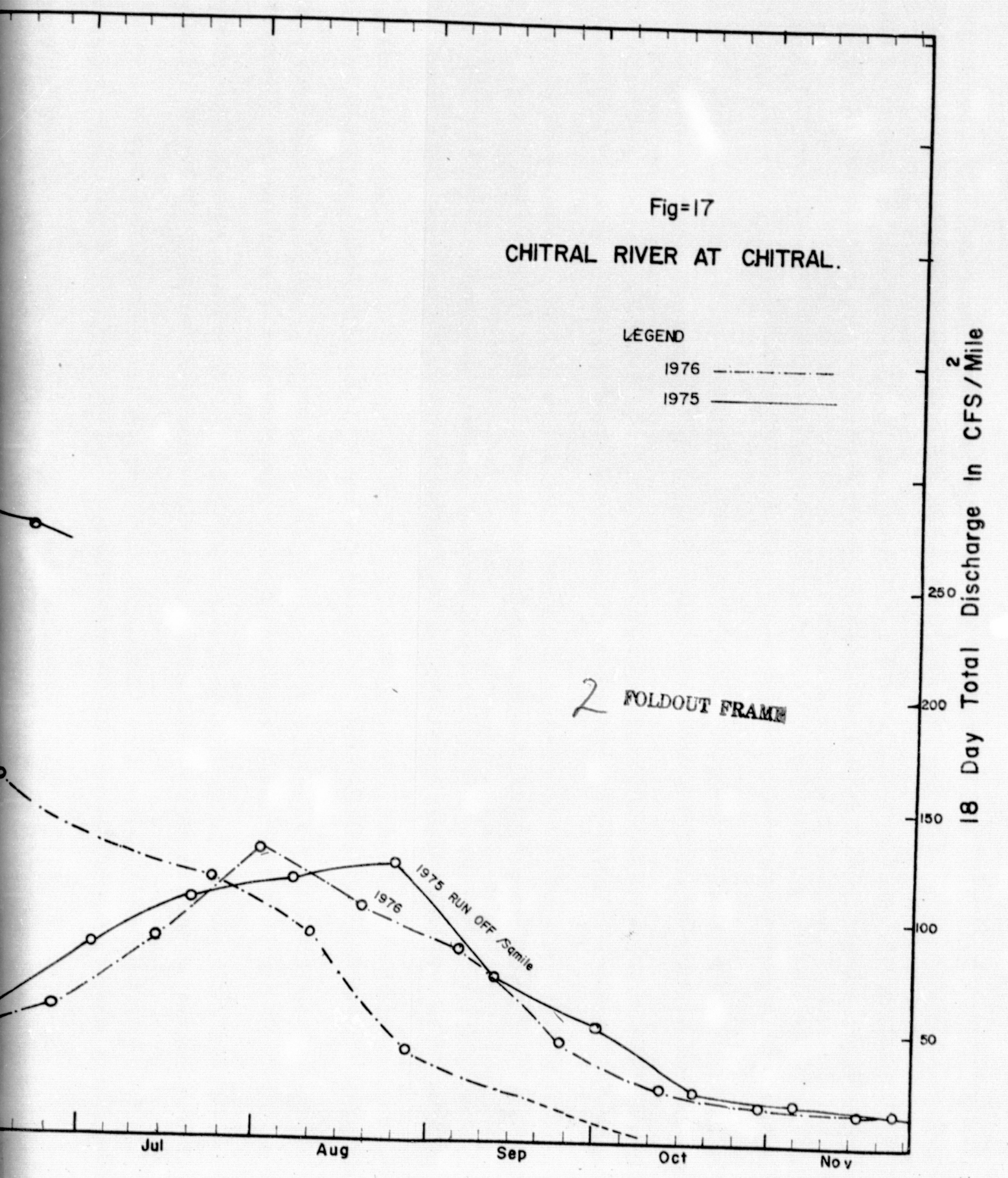
2 FOLDOUT FRAME



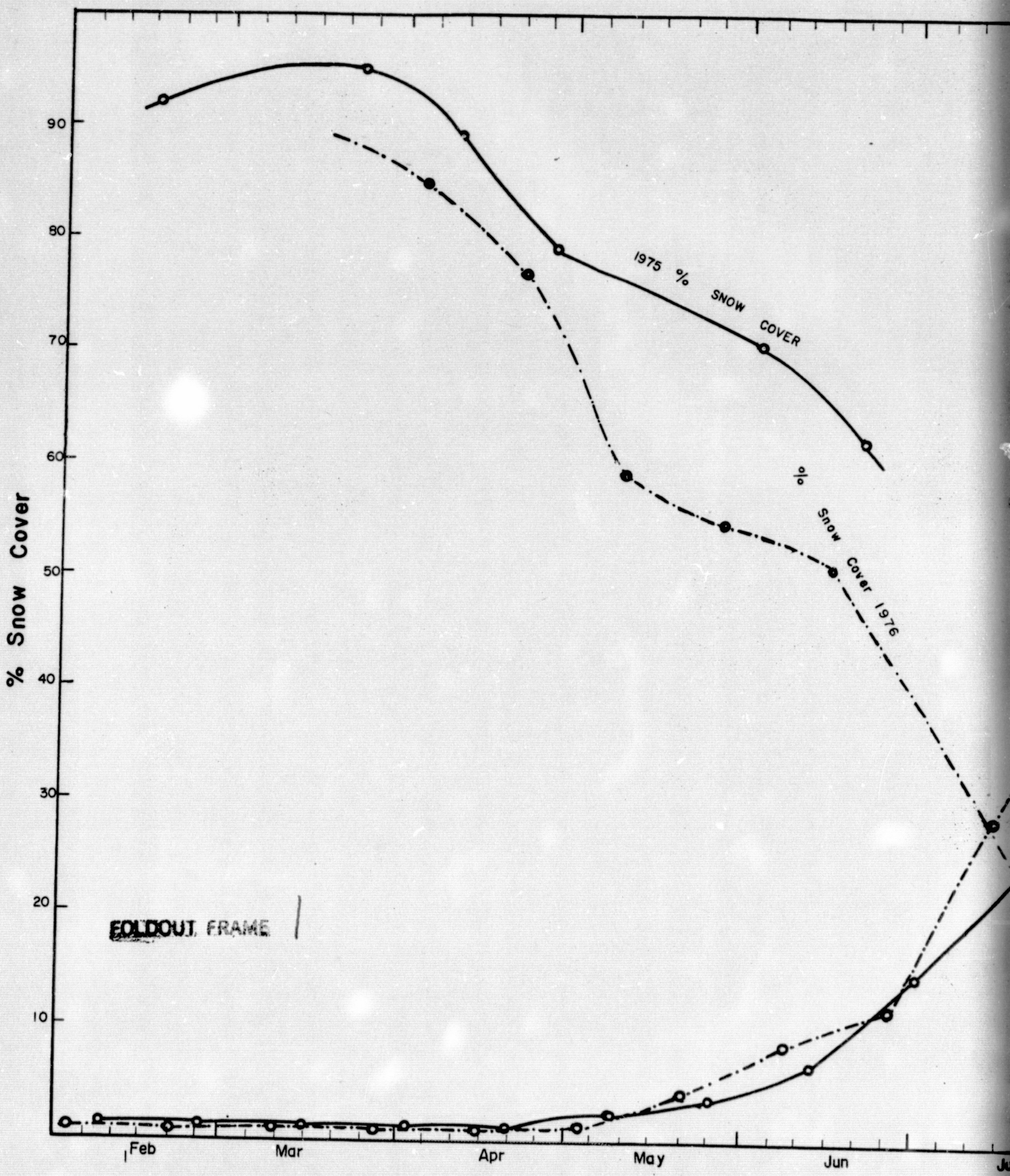
FOLDOUT FRAME

Fig=17

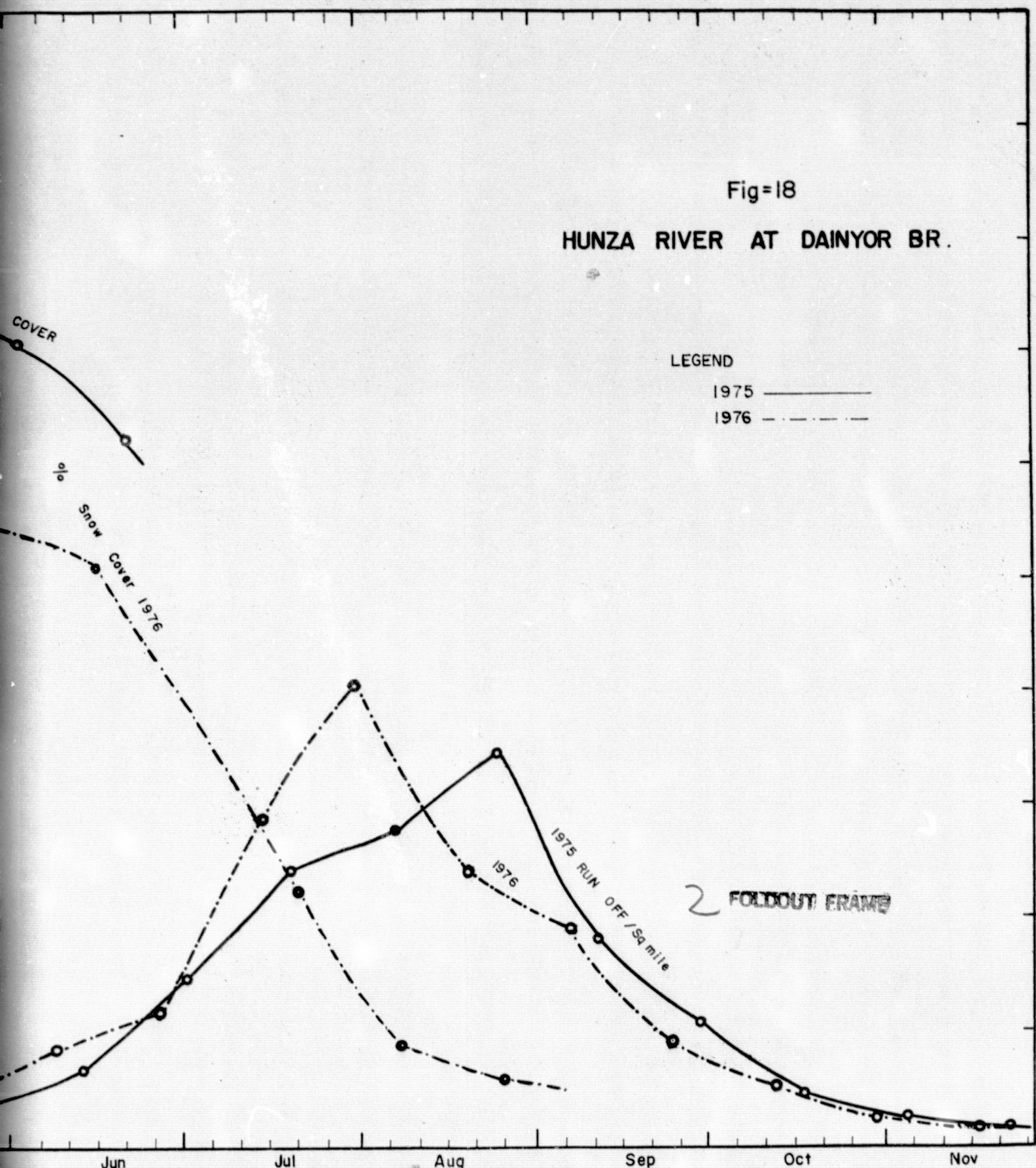
CHITRAL RIVER AT CHITRAL.

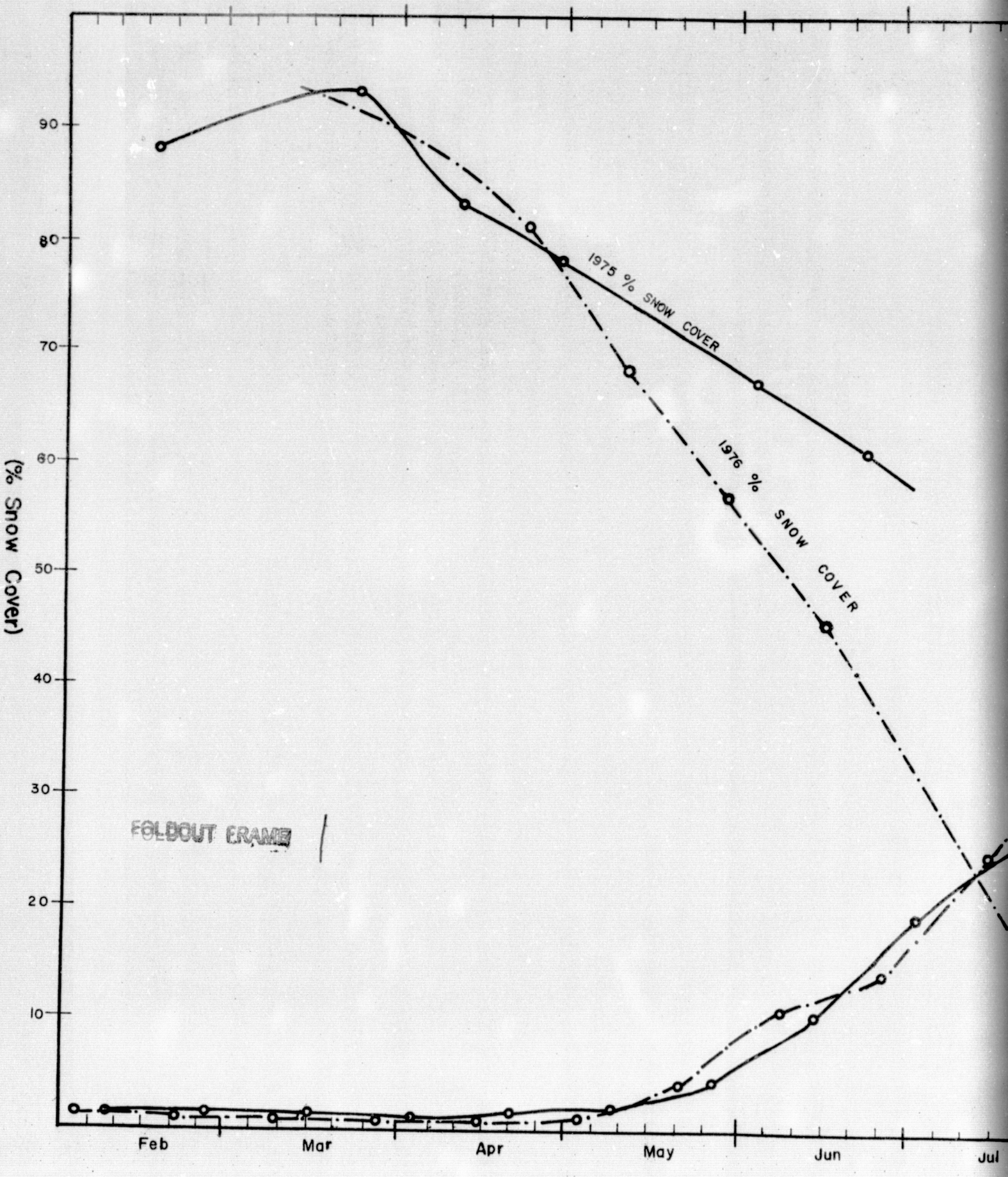


2 FOLDOUT FRAME



FOLDOUT FRAME

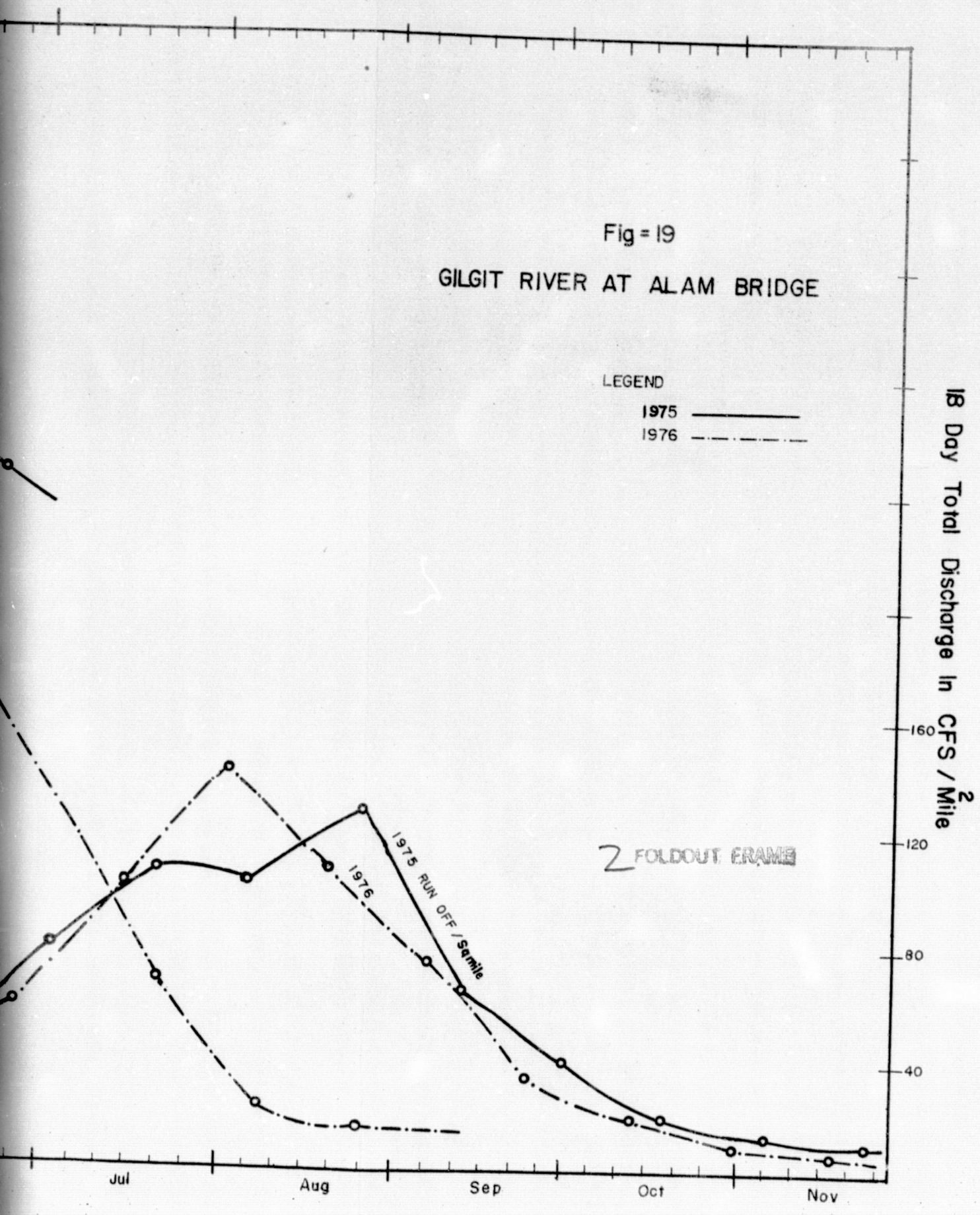

Fig=18
HUNZA RIVER AT DAINYOR BR.
LEGEND
1975
1976
COVER
% Snow Cover 1976
1975 RUN OFF / Sq mile
1976
FOLDOUT FRAME 2
18 Day Total Discharge In CFS/Mile²
250
200
150
100
50
Jun
Jul
Aug
Sep
Oct
Nov



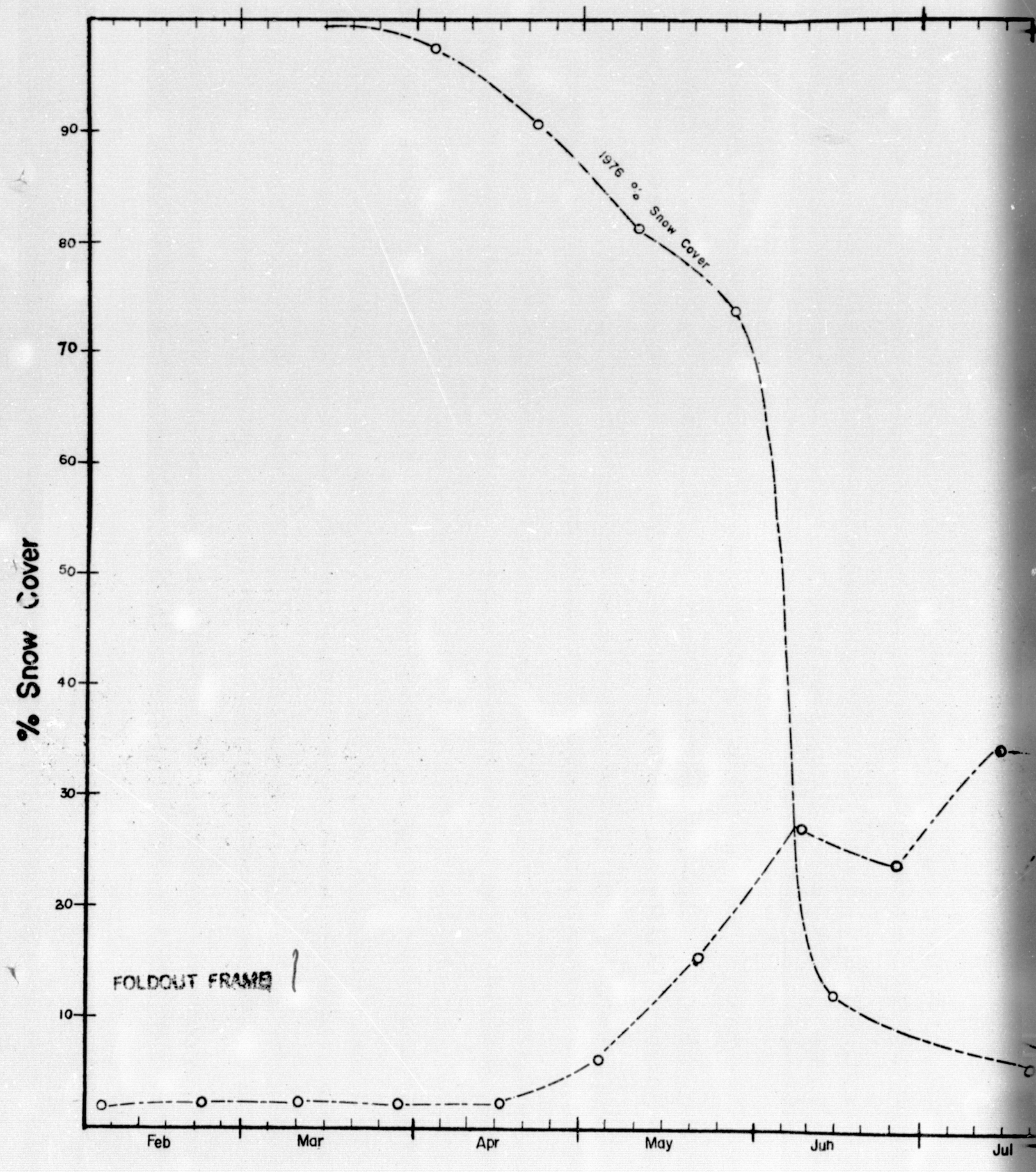
FOLDOUT FRAME

Fig = 19

GILGIT RIVER AT ALAM BRIDGE



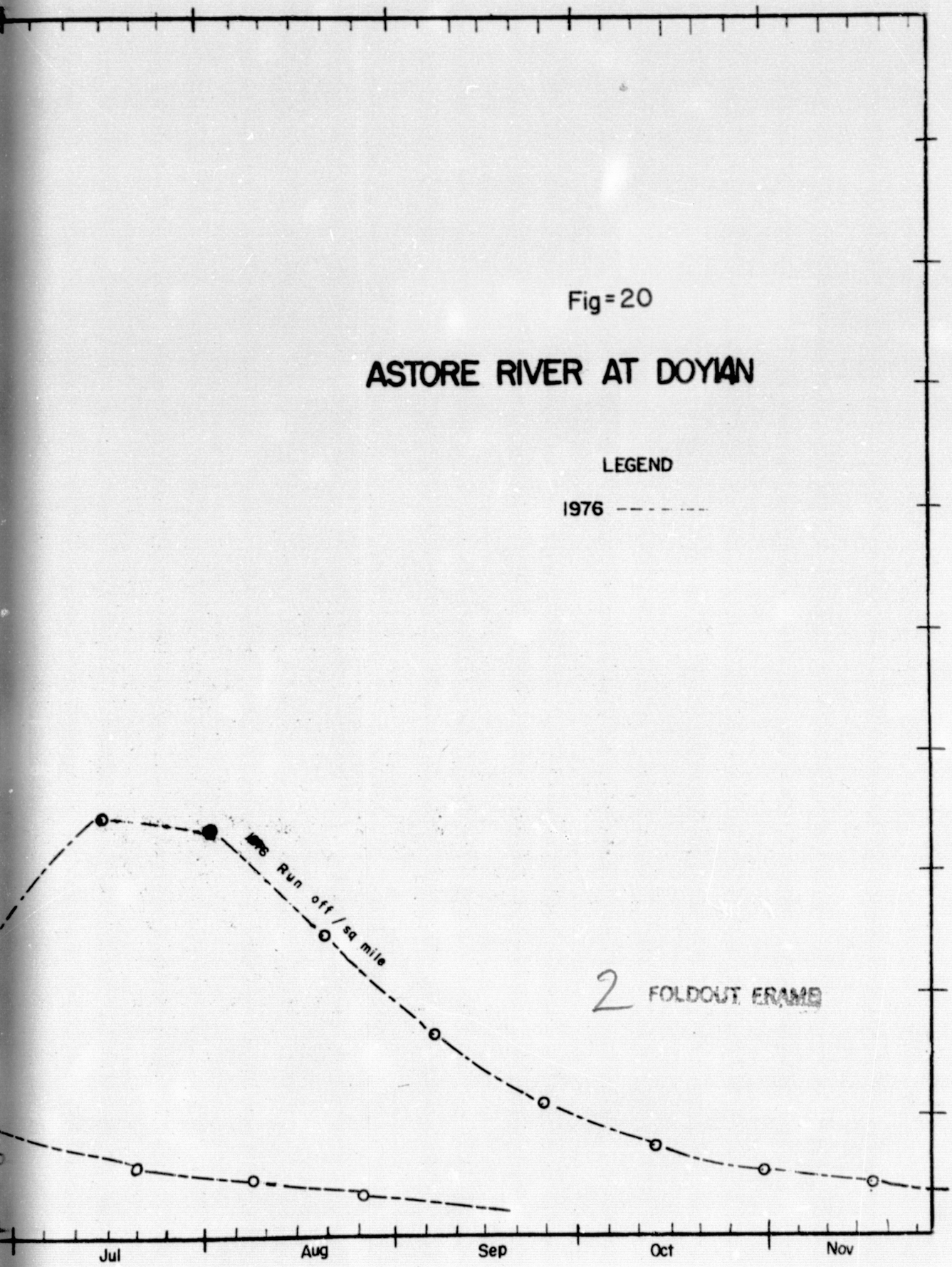
2 FOLDOUT FRAME



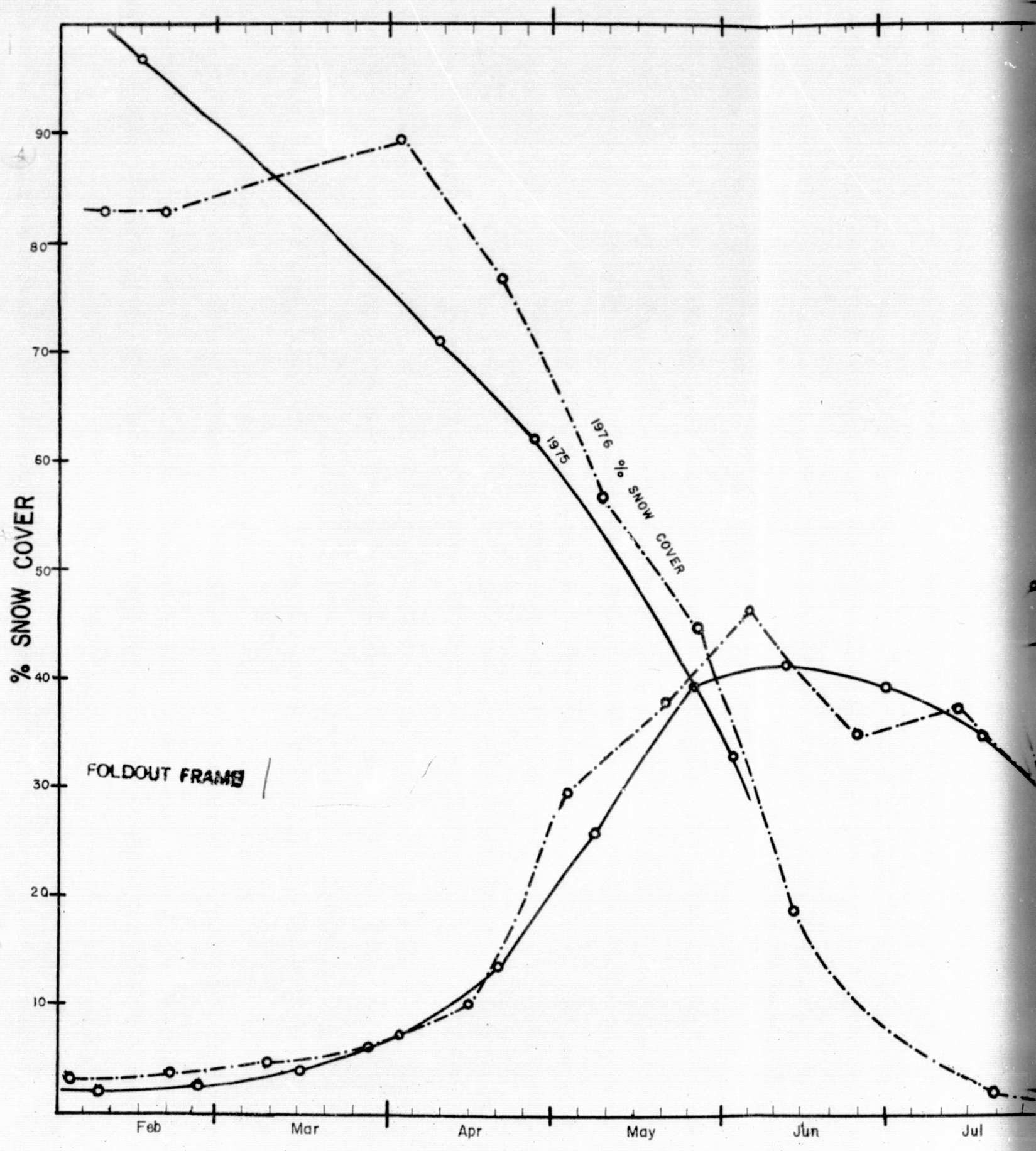
FOLDOUT FRAME 1

Fig=20

ASTORE RIVER AT DOYIAN

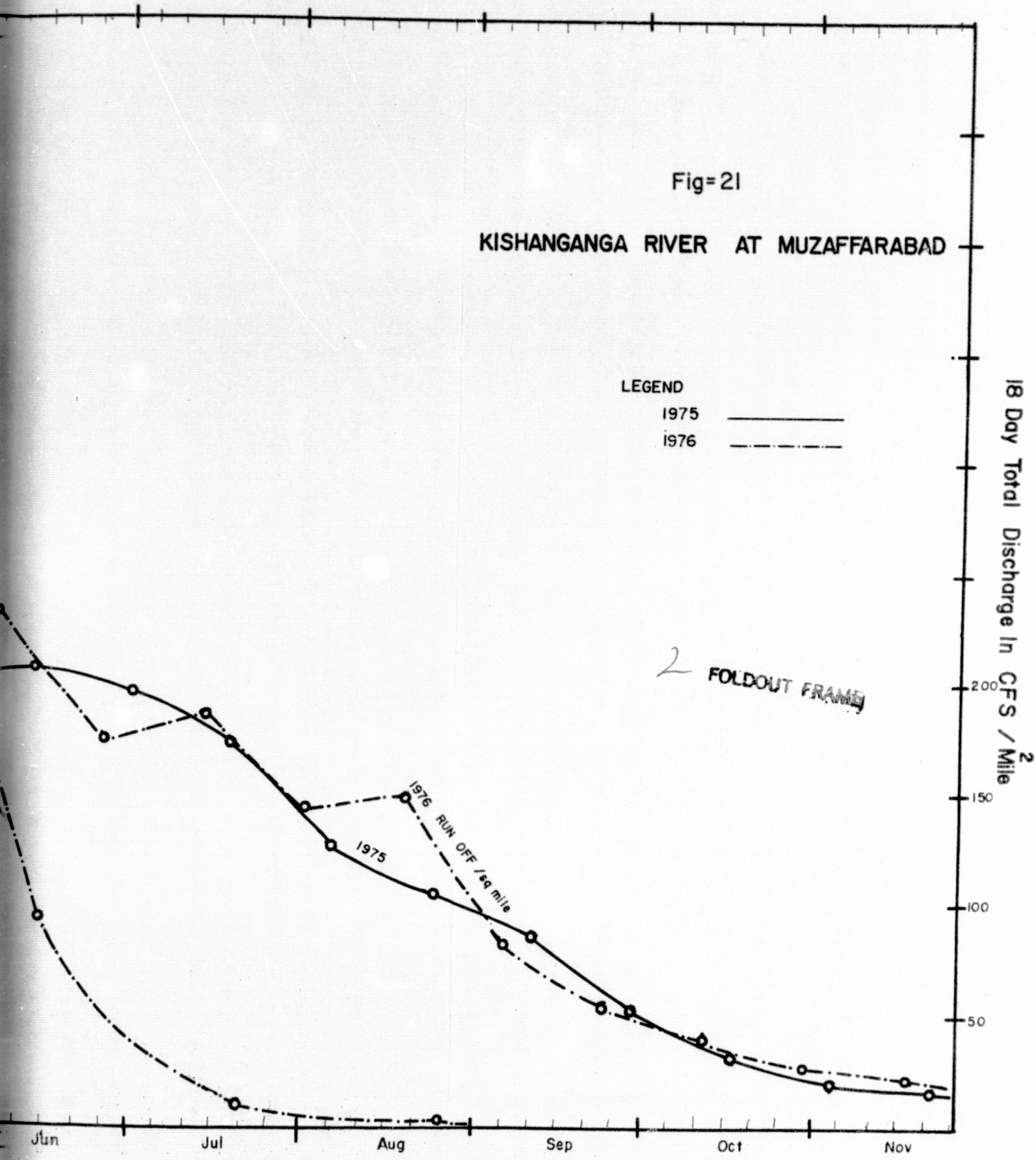


2 FOLDOUT FRAME

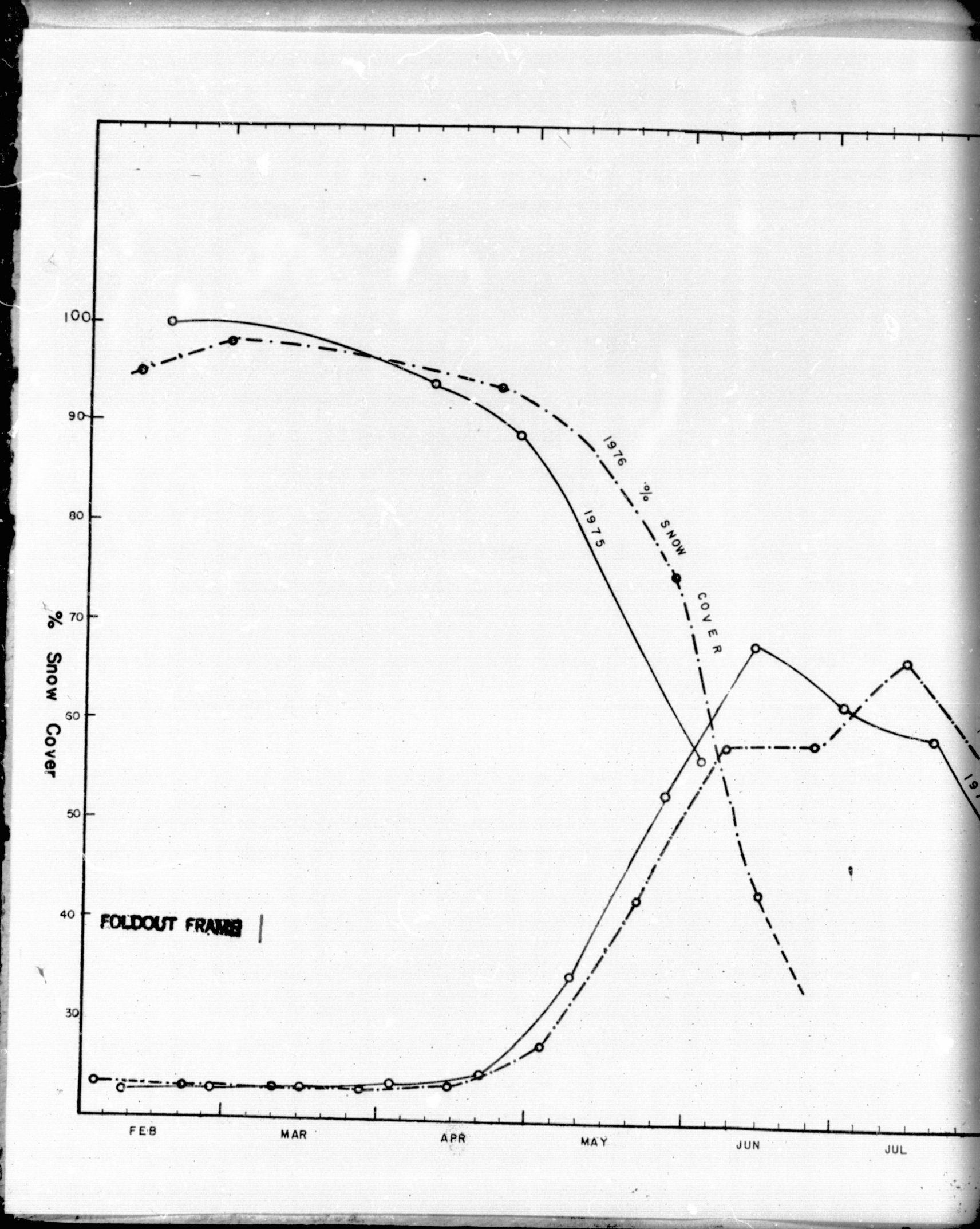

% SNOW COVER
90
80
70
60
50
40
30
20
10
1976 % SNOW COVER
1975
FOLDOUT FRAME
Feb
Mar
Apr
May
Jun
Jul

Fig=21

KISHANGANGA RIVER AT MUZAFFARABAD

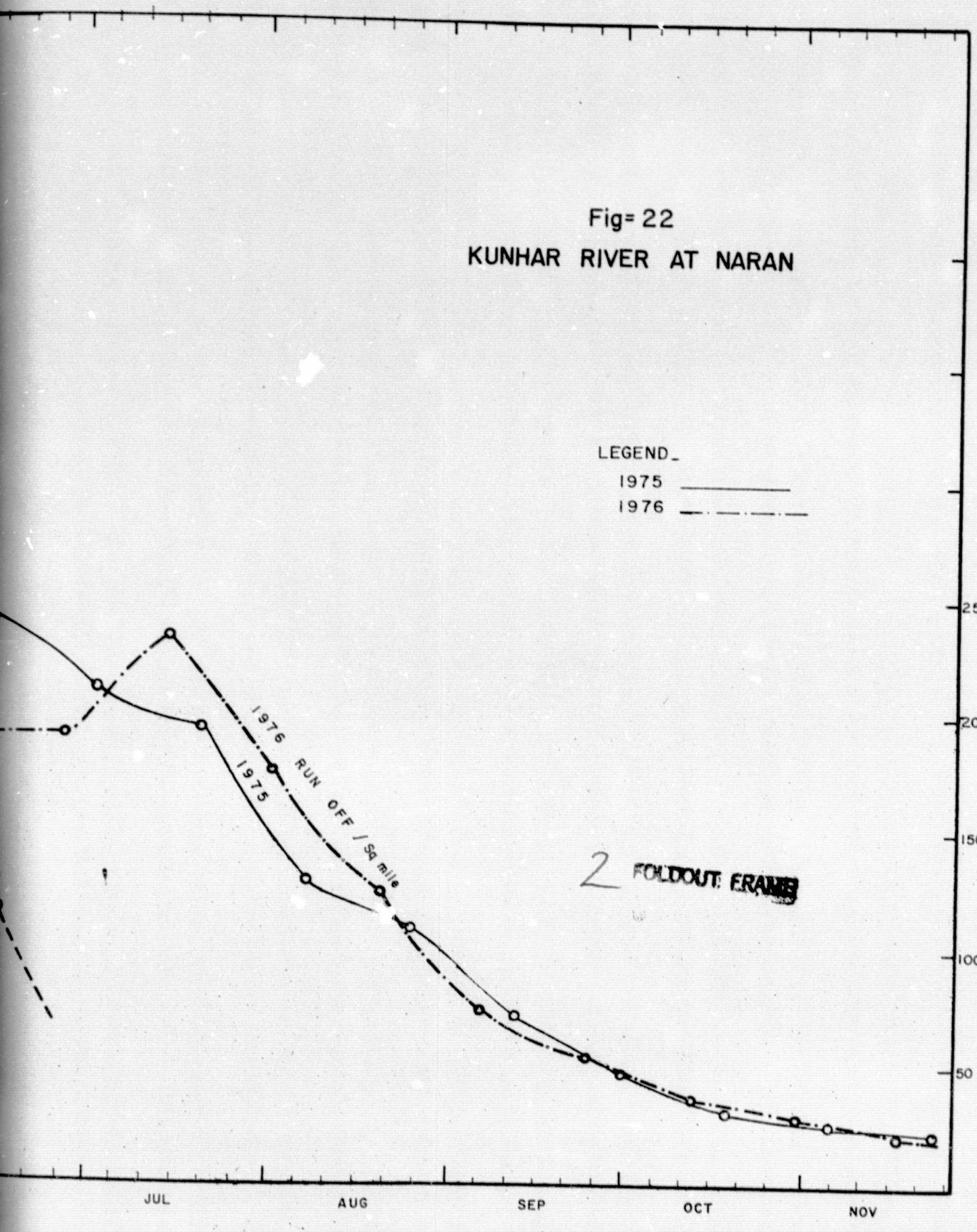


2 FOLDOUT FRAME


100
90
80
70
60
50
40
30
% Snow Cover
1976 % SNOW COVER
1975
FEB
MAR
APR
MAY
JUN
JUL
FOLDOUT FRAME

Fig= 22

KUNHAR RIVER AT NARAN



2 FOLDOUT FRAMES

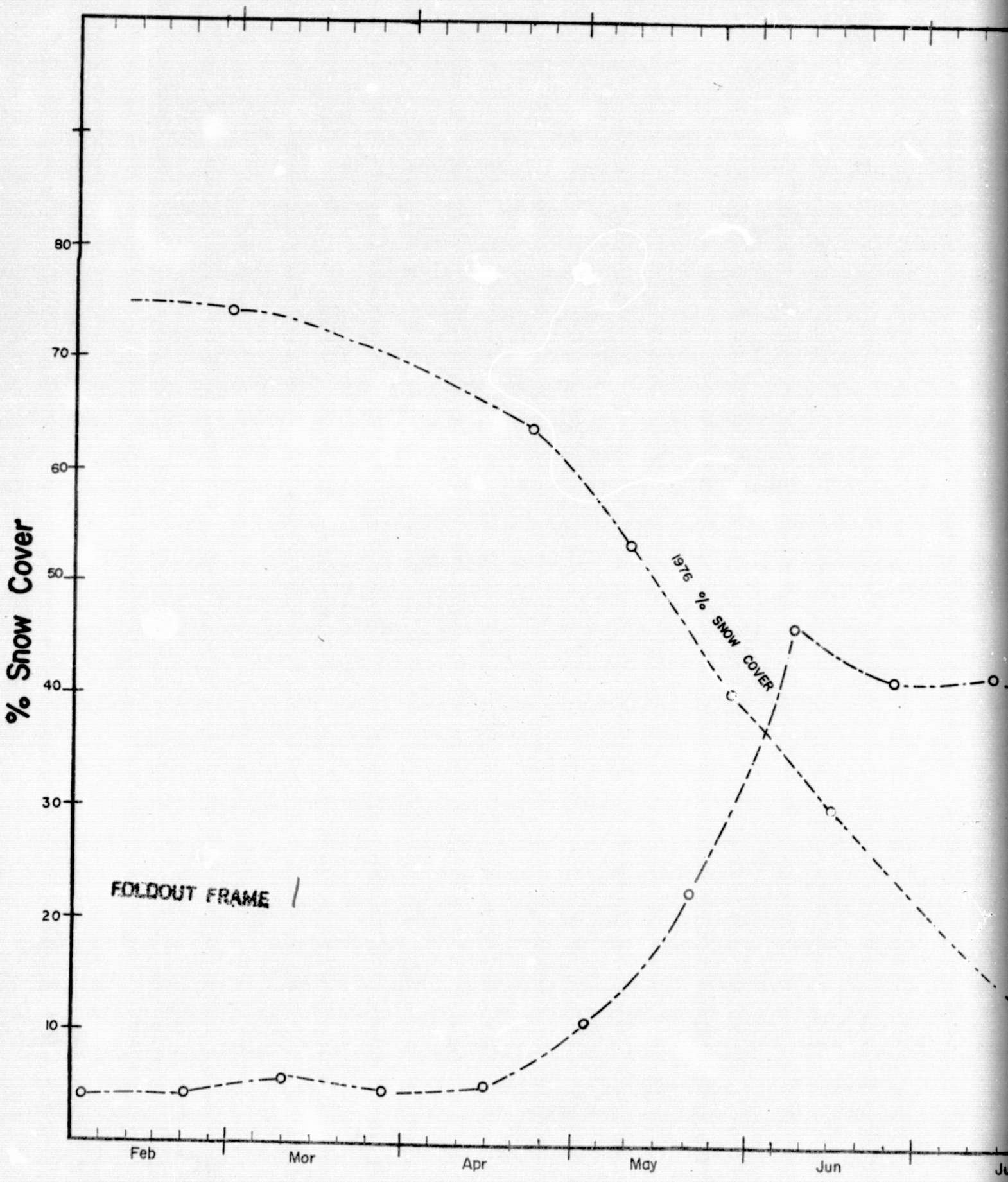
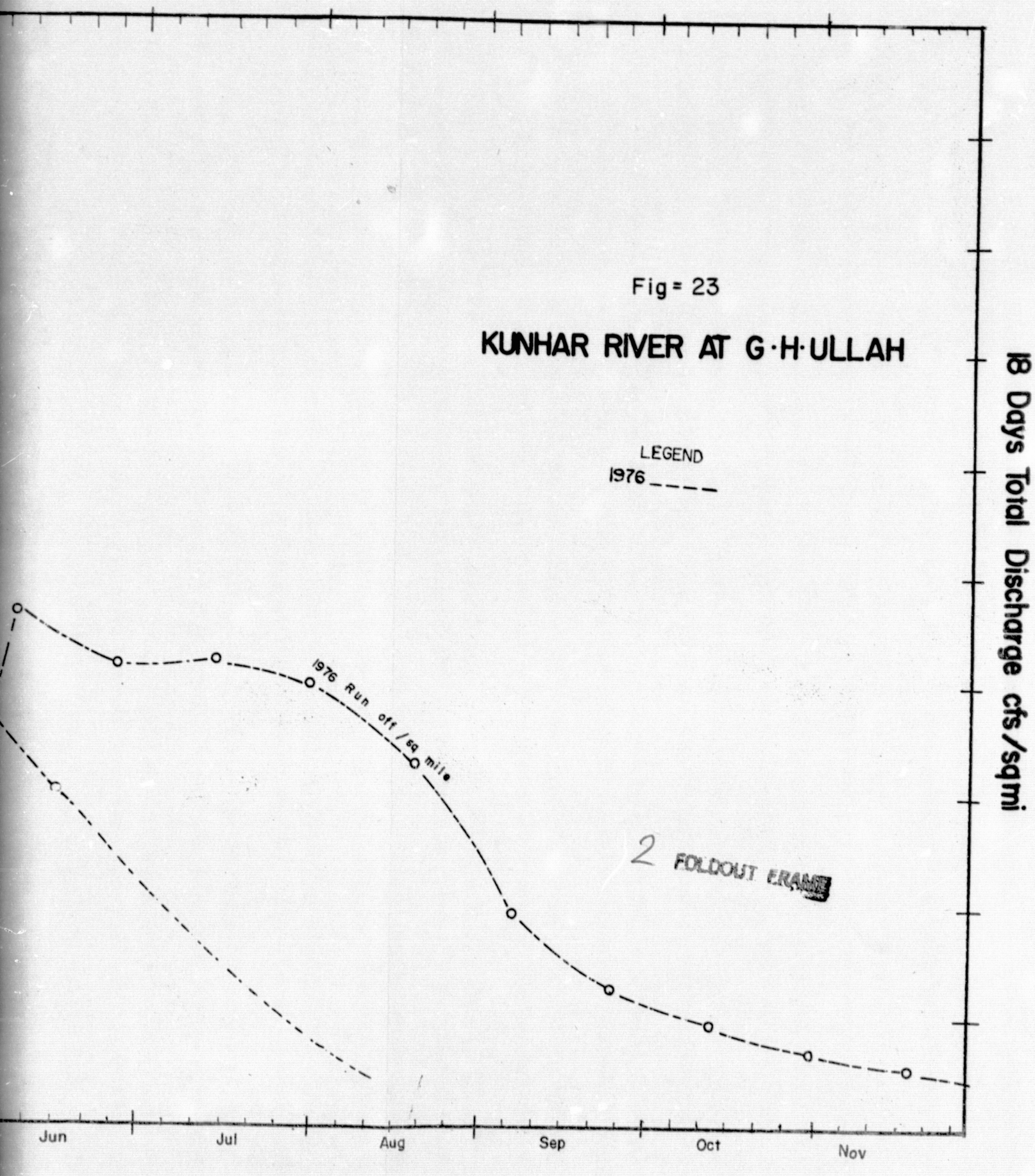
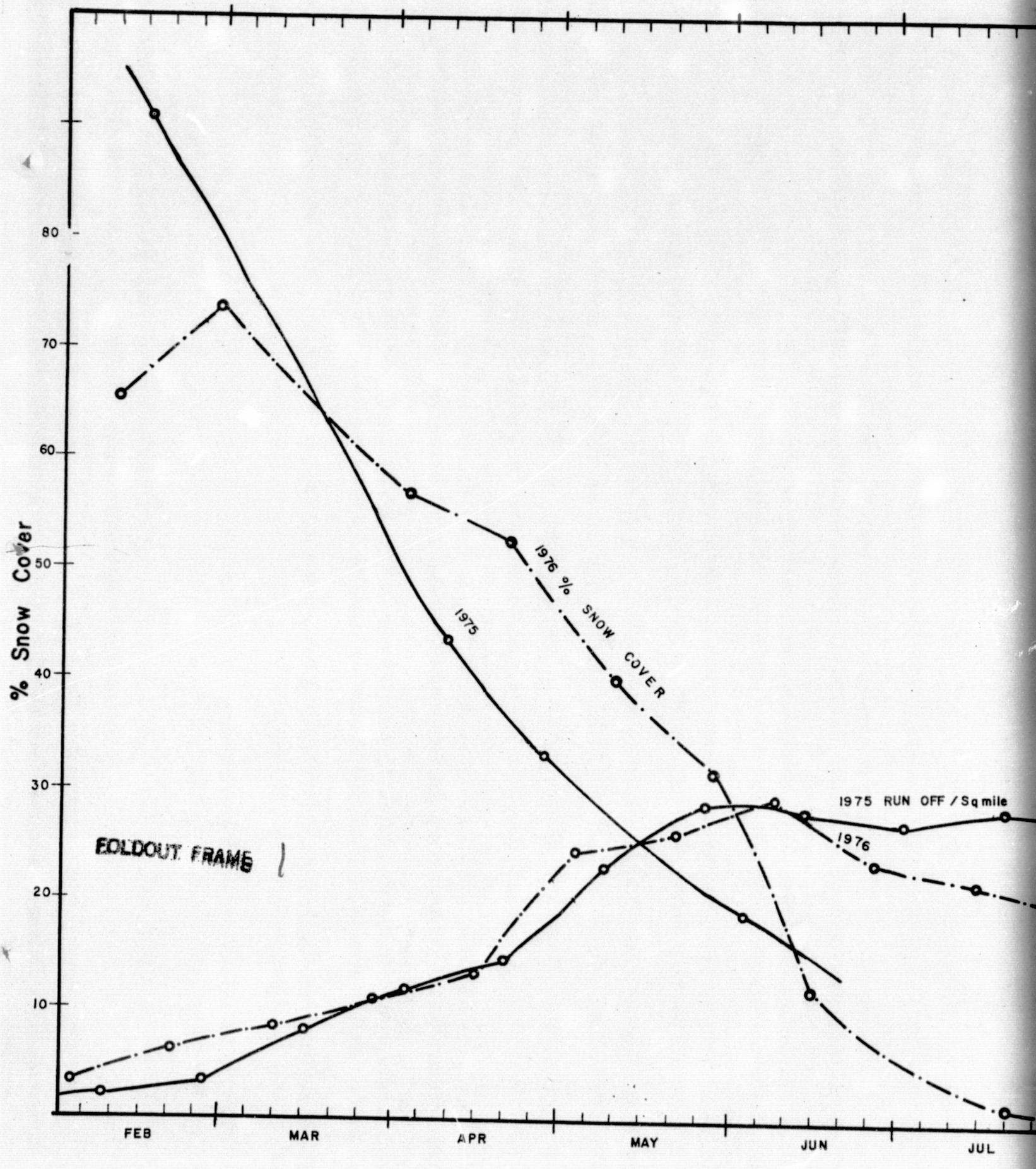

% Snow Cover
80
70
60
50
40
30
20
10
1976 % SNOW COVER
FOLDOUT FRAME
Feb
Mor
Apr
May
Jun

Fig = 23

KUNHAR RIVER AT G·H·ULLAH



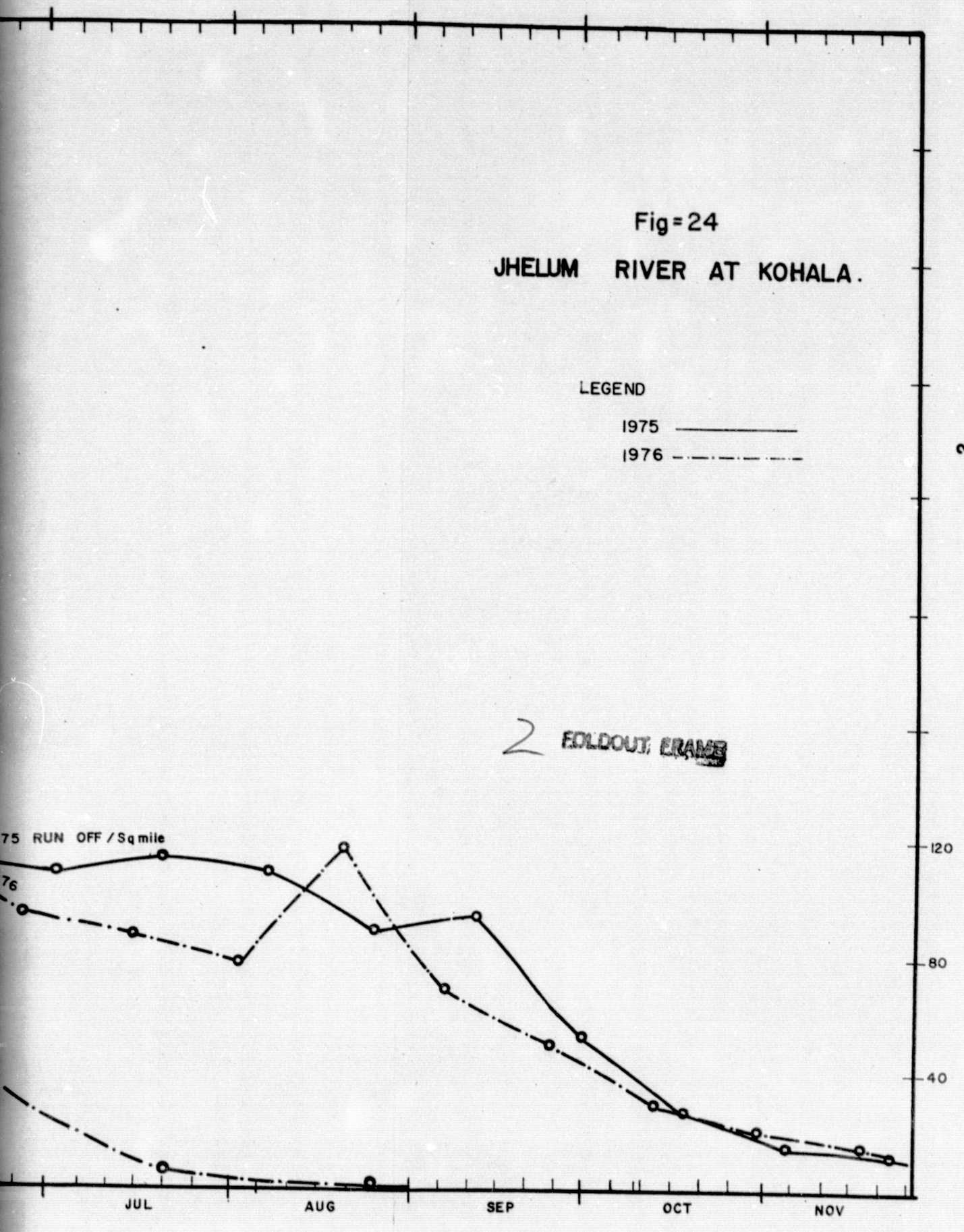
2 FOLDOUT FRAME



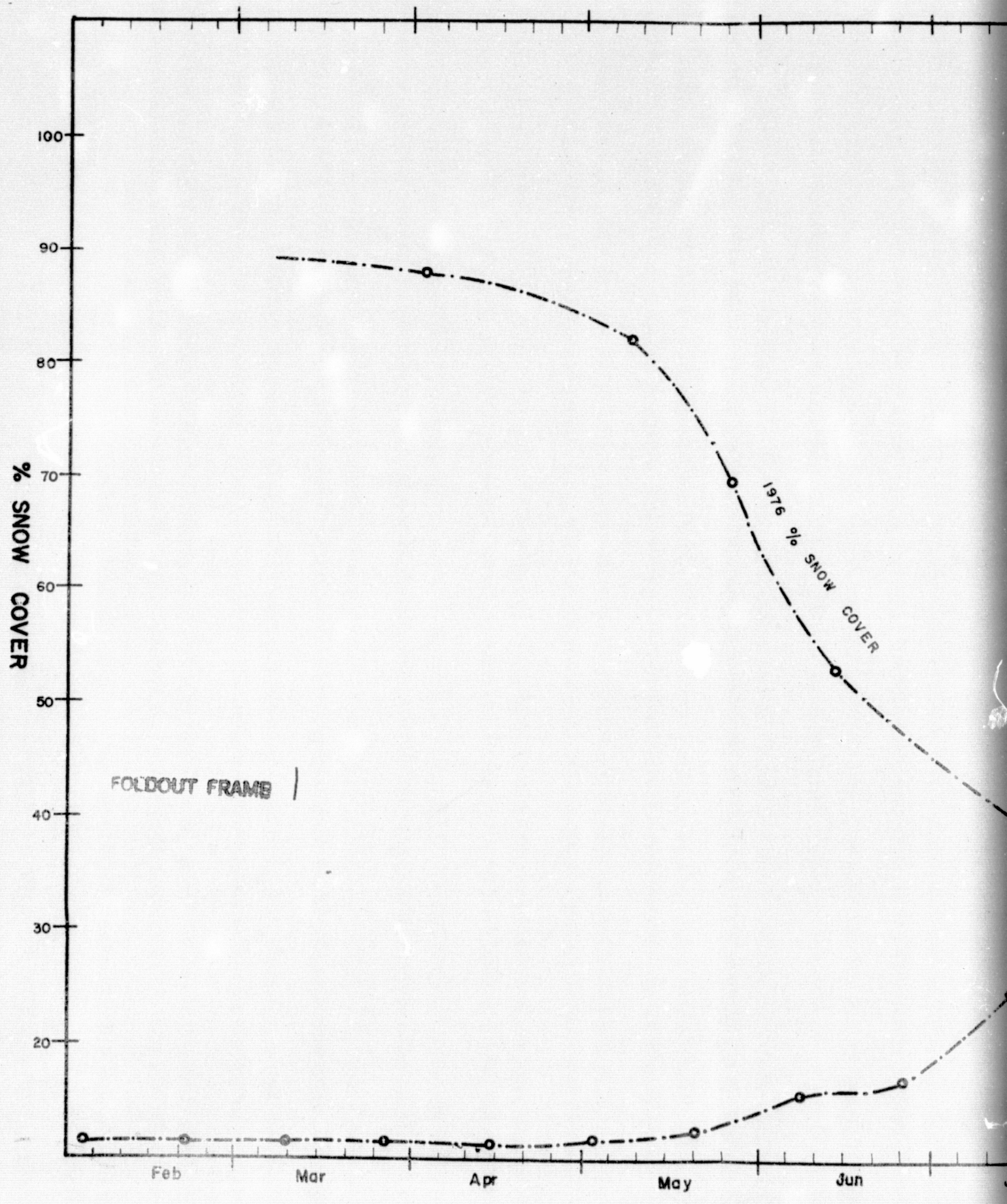
FOLDOUT FRAME 1

Fig=24

JHELUM RIVER AT KOHALA.

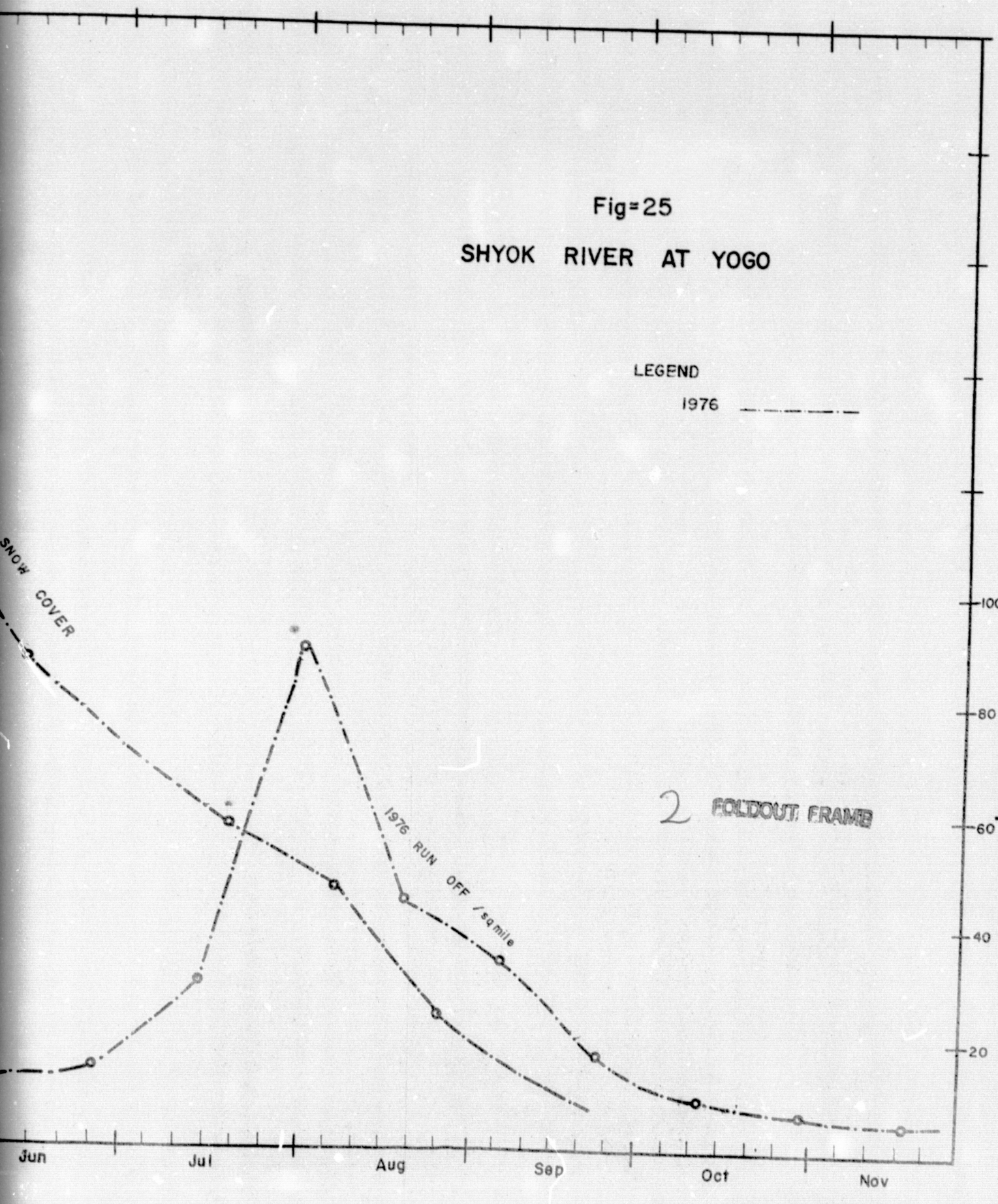


2 FOLDOUT FRAME


100
90
80
70
60
50
40
30
20
% SNOW COVER
1976 % SNOW COVER
FOLDOUT FRAME
Feb
Mar
Apr
May
Jun

Fig=25

SHYOK RIVER AT YOGO



2 FOLDOUT FRAME

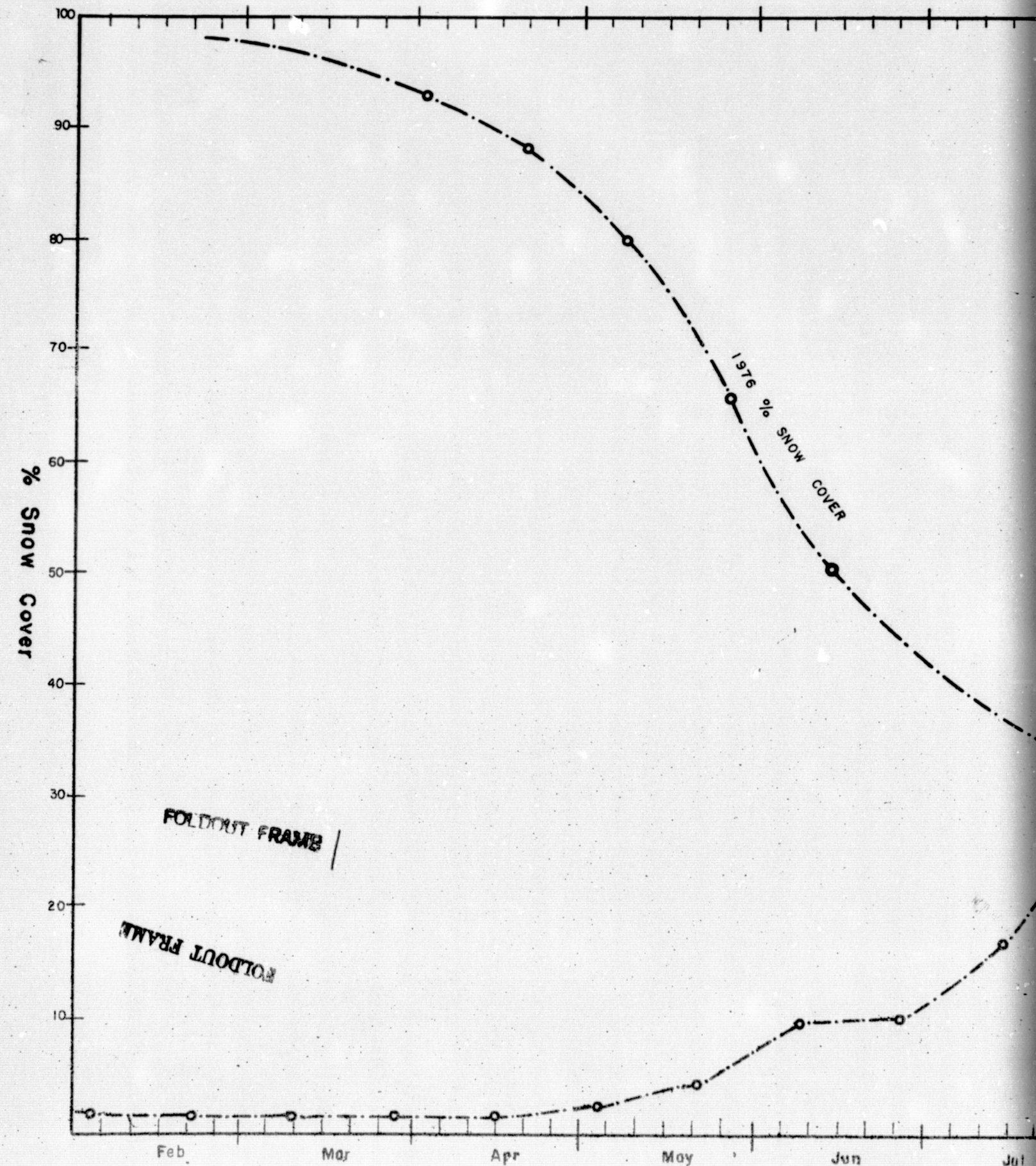
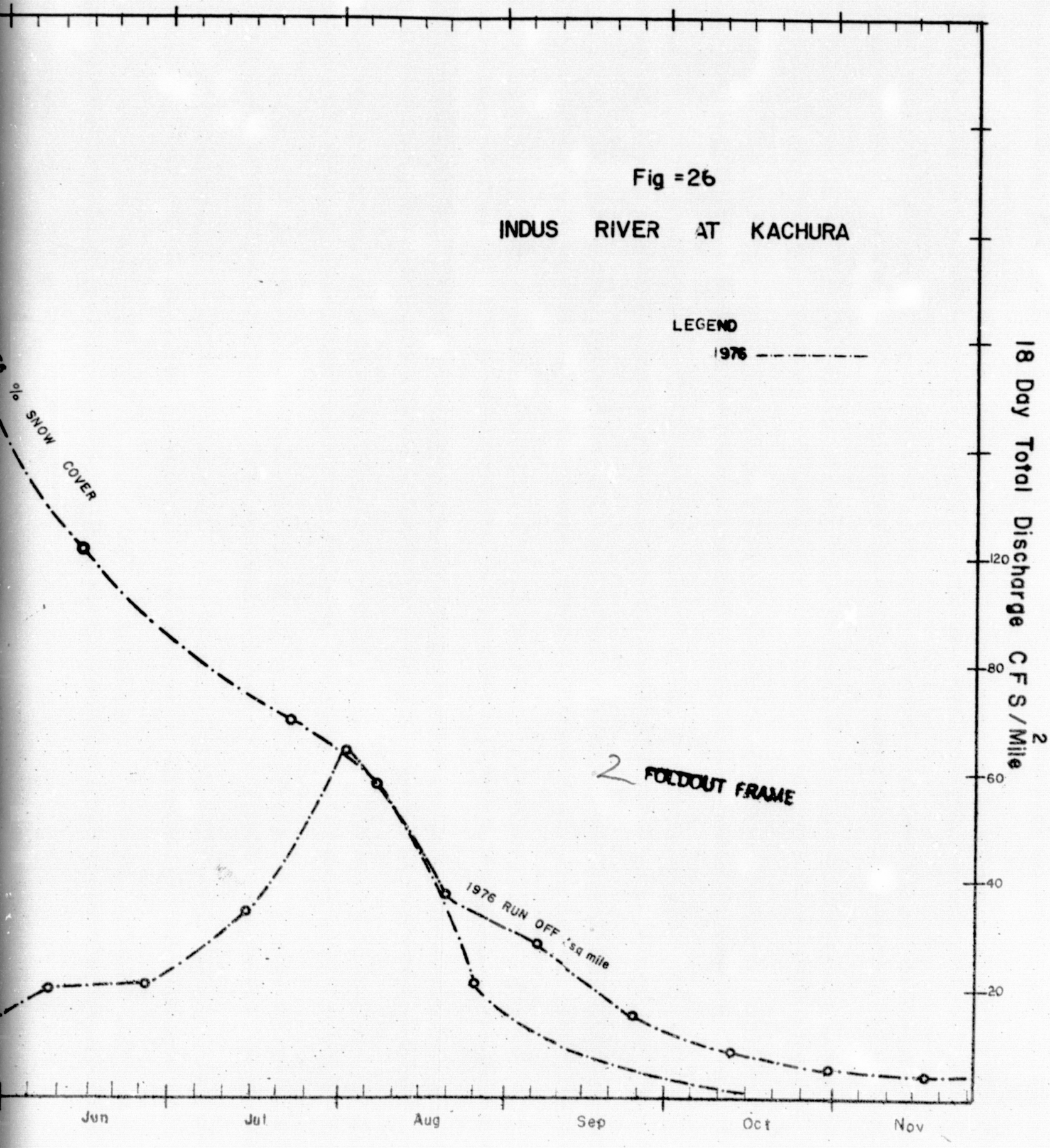
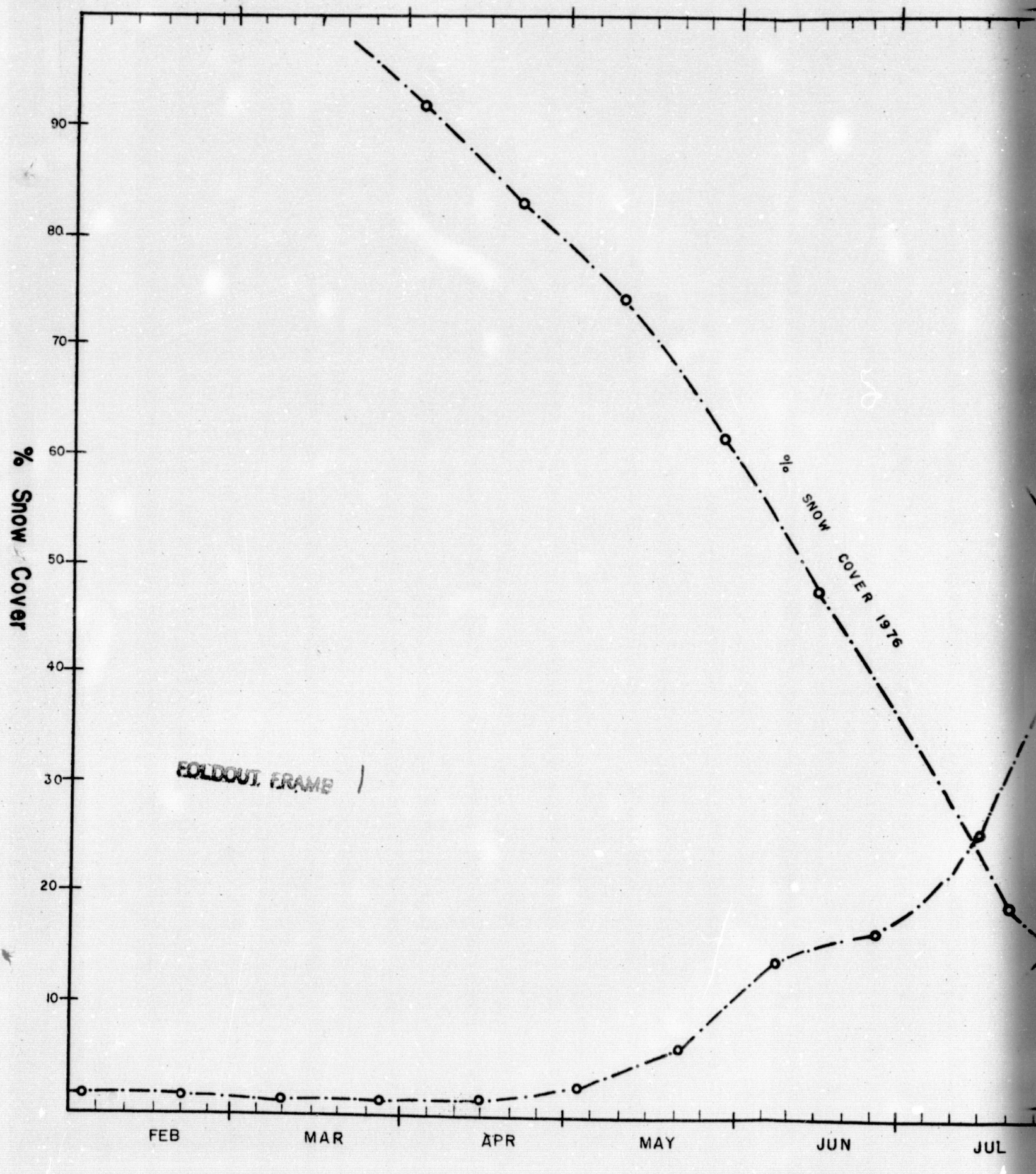

100
90
80
70
60
50
40
30
20
10
% Snow Cover
1976 % SNOW COVER
FOLDOUT FRAME
FOLDOUT FRAME
Feb
Mar
Apr
May
Jun
Jul

Fig =26

INDUS RIVER AT KACHURA



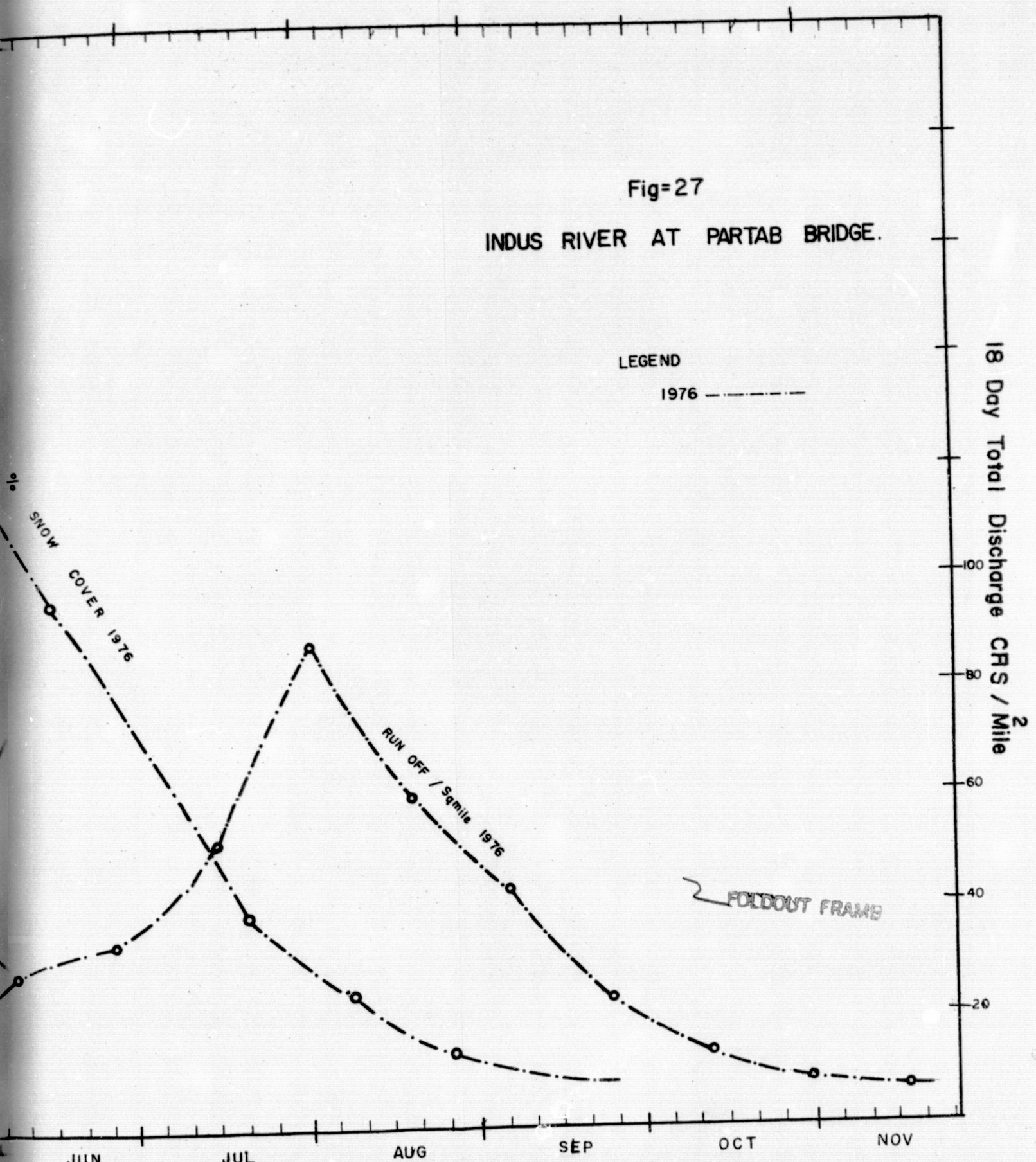
2 FOLDOUT FRAME



FOLDOUT FRAME 1

Fig=27

INDUS RIVER AT PARTAB BRIDGE.



FOLDOUT FRAME

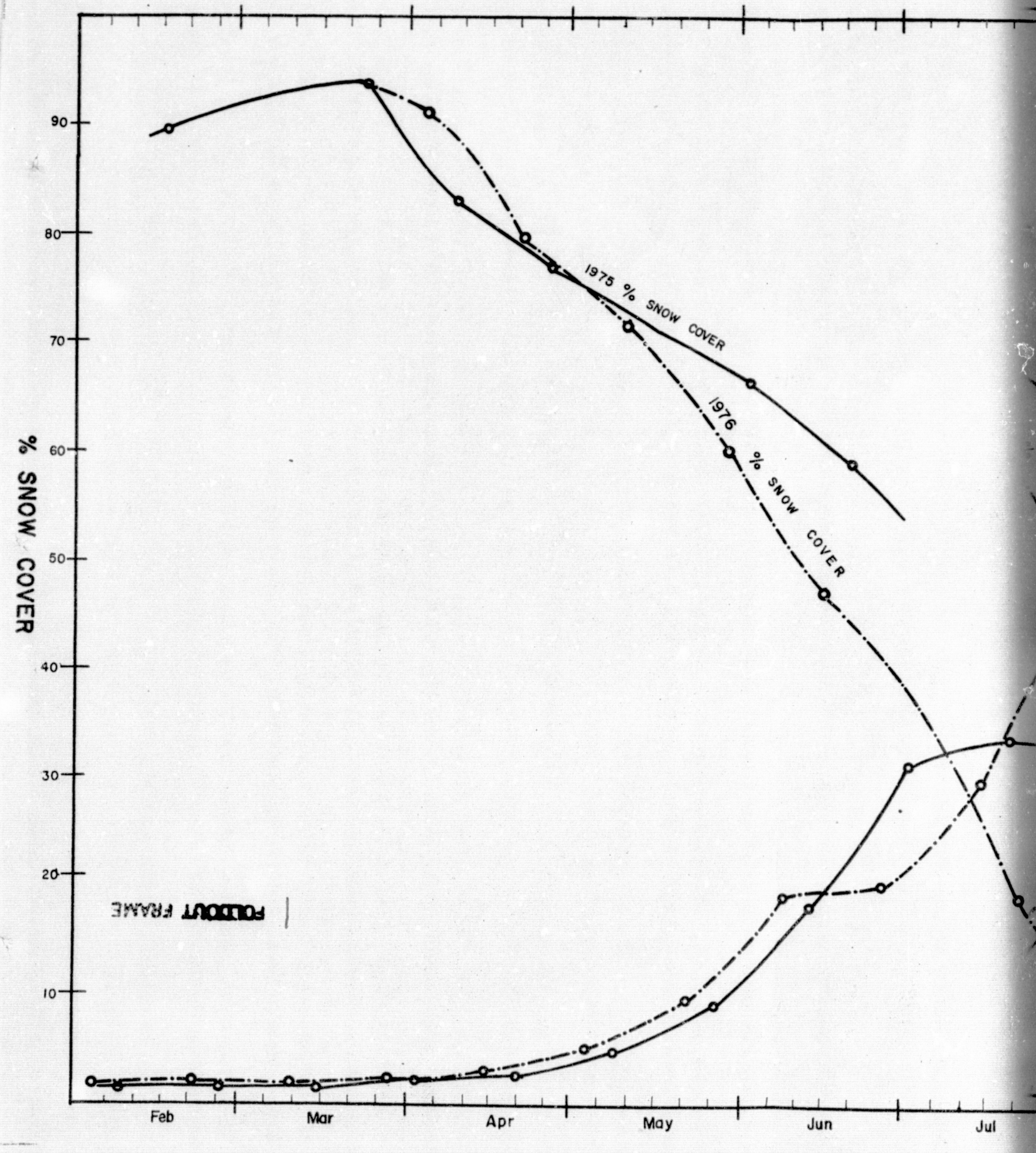
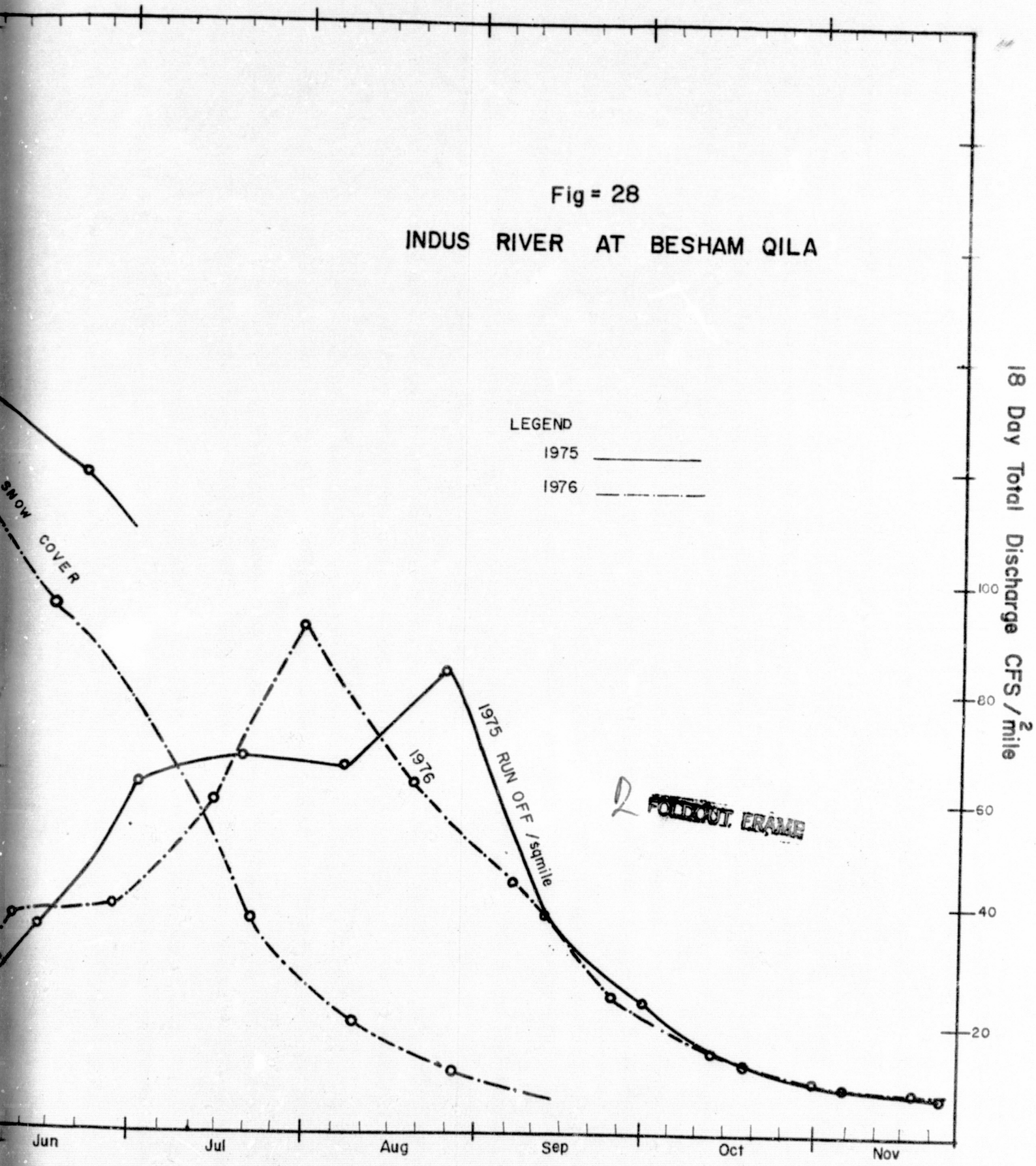
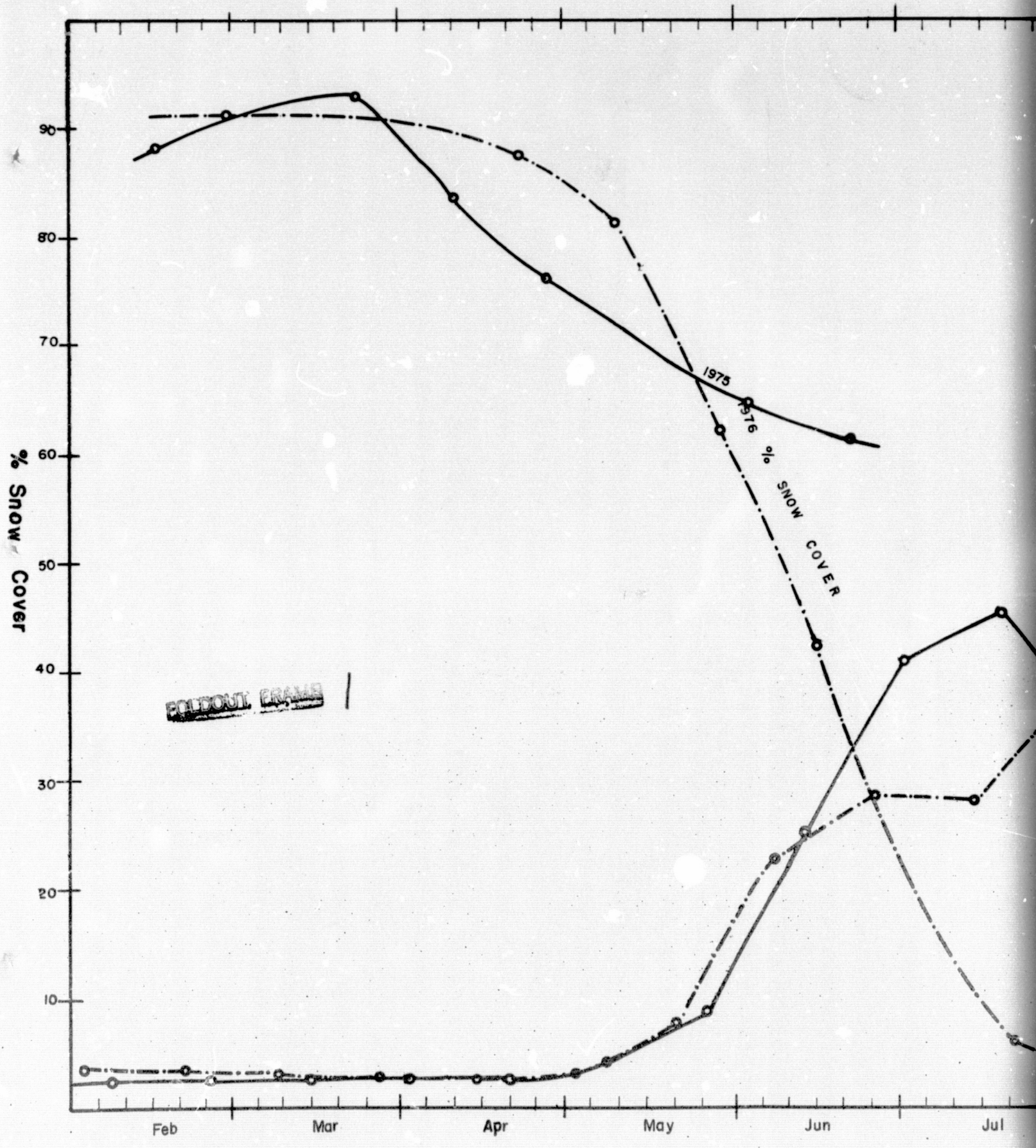

% SNOW COVER
90
80
70
60
50
40
30
20
10
1975 % SNOW COVER
1976 % SNOW COVER
FOLDOUT FRAME
Feb
Mar
Apr
May
Jun
Jul

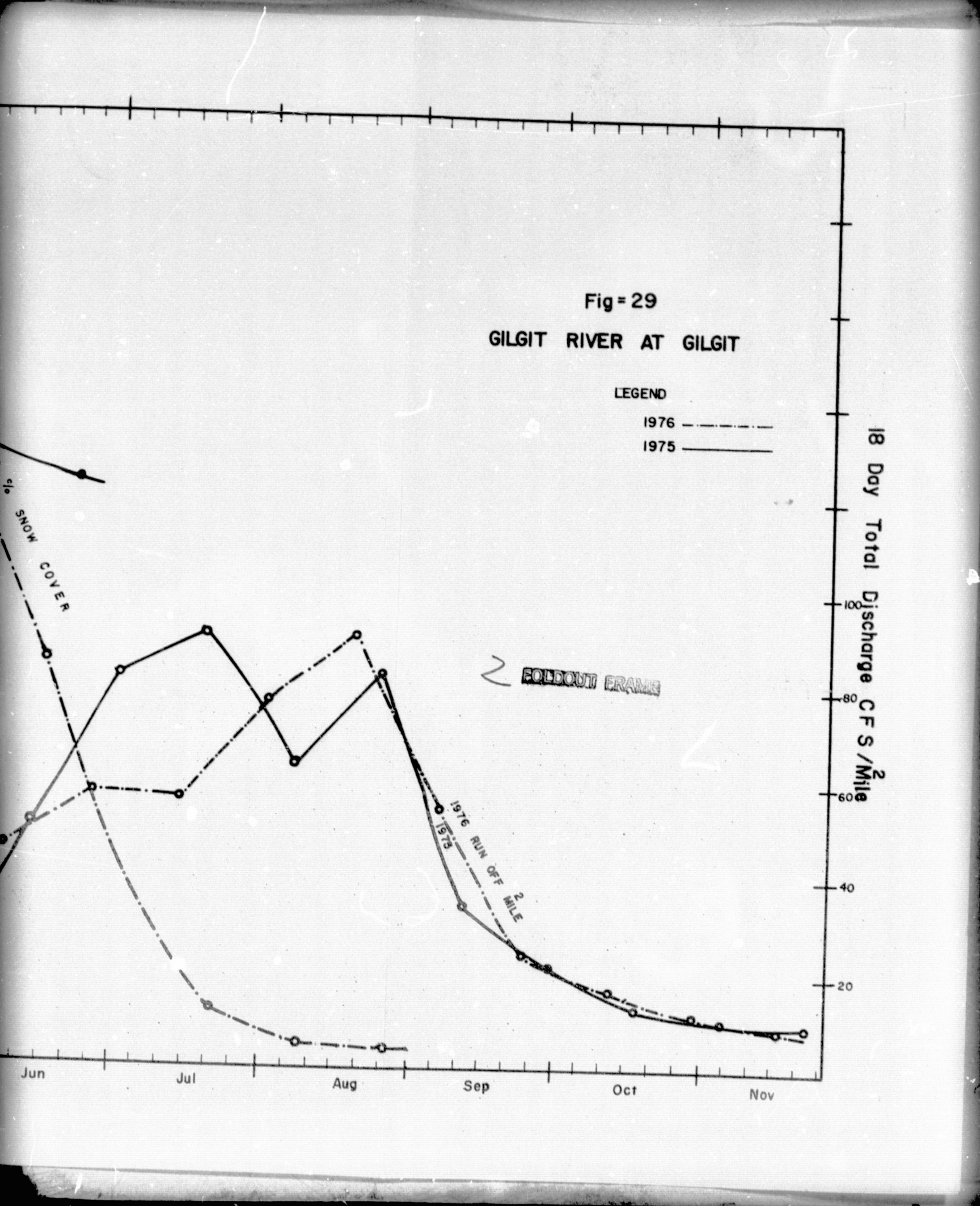
Fig = 28

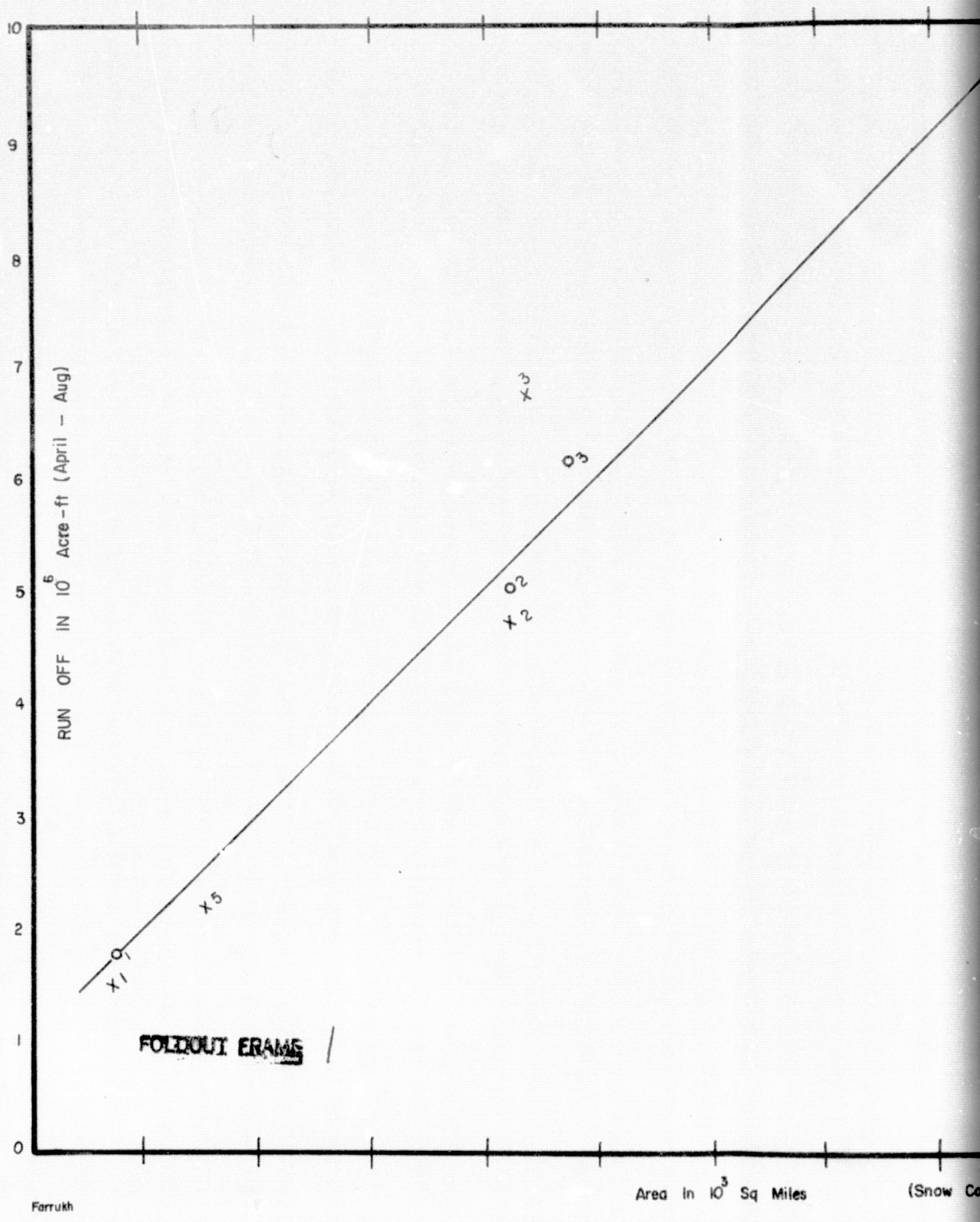
INDUS RIVER AT BESHAM QILA



FOLDOUT FRAME


90
80
70
60
50
40
30
20
10
% Snow Cover
1975
1976
% SNOW COVER
FOLDOUT FRAME
Feb
Mar
Apr
May
Jun
Jul


Fig = 29
GILGIT RIVER AT GILGIT
LEGEND
1976
1975
18 Day Total Discharge CFS/Mile²
100
80
60
40
20
SNOW COVER
1976 RUN OFF 2 MILE
1975
FOLDOUT FRAME
Jun
Jul
Aug
Sep
Oct
Nov



FOLDOUT FRAME

Farrukh

GROUP I

$R = 0.847 + 1.075A$

$r^2 = 0.972$

R = Apr - Aug Snow Melt Run Off

In MAF

A = Area Under Snow On Ist of April

In 1000 sq. Miles

List Of Stations

1. Swat River Nr Kalam
2. Chitral River At Chitral
3. Hunza River At Dainyor Bridge
4. Gilgit River At Alam Bridge
5. Astore River At Doyian

FIG 30

LAND SAT-2 DERIVED SNOW COVER
ESTIMATES MEASURED RUN OFF 1975 & 76.

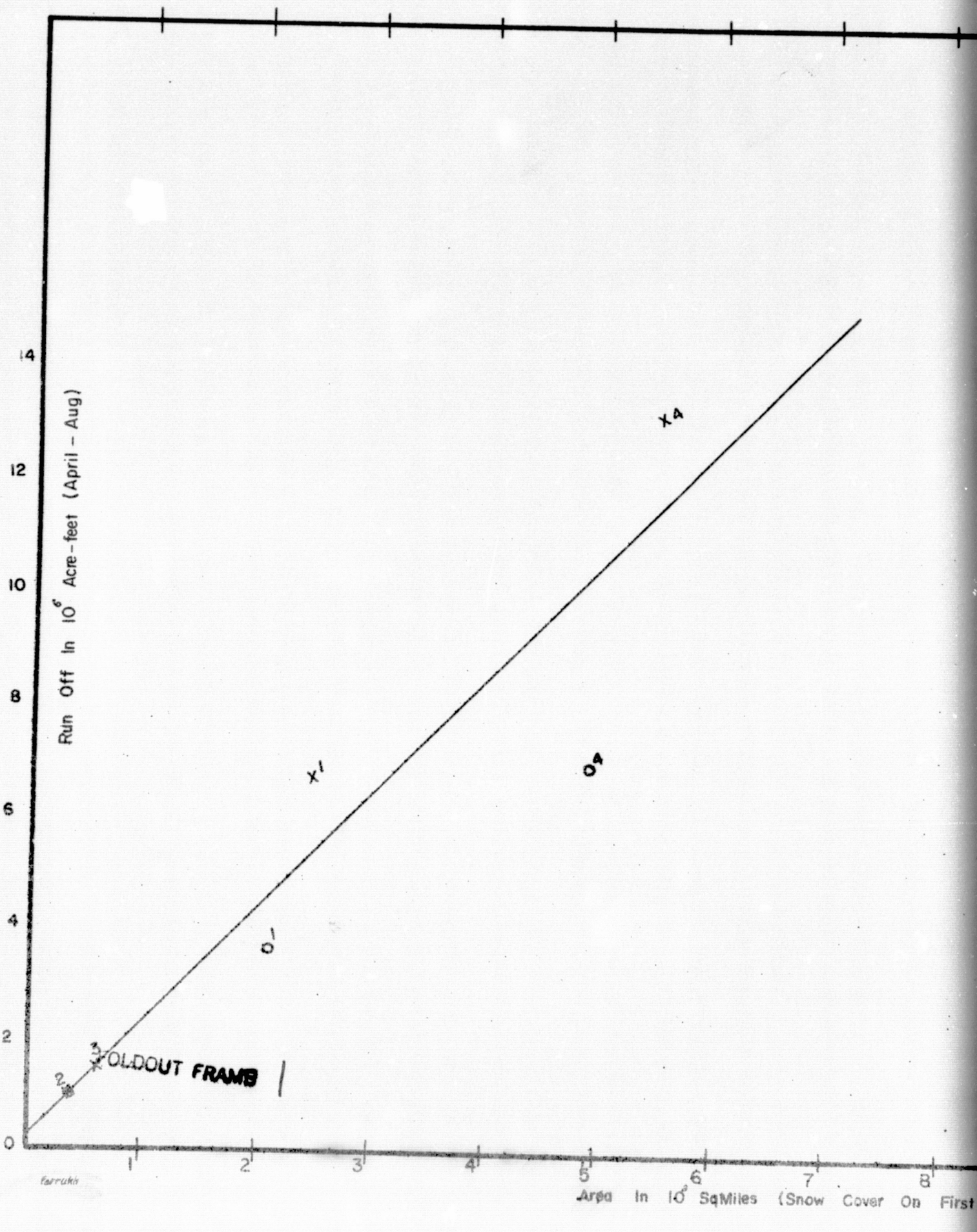
LEGEND

O ---- 1975

X ------- 1976

2 FOLDOUT FRAME

Miles (Snow Cover On First Of April)


Run Off In 10^6 Acre-feet (April - Aug)
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
Area In 10^3 SqMiles (Snow Cover On First
X4
X1
O4
O1
3
2
FOLDOUT FRAME 1
farrukh

GROUP II

$R = 0.208 + 1.95IA$

$r^2 = 0.865$

R = Apr – Aug Snow Melt Run - Off In MAF

A = Area Under Snow On Ist Of April In 1000 Sq Miles

List Of Station

1. Kishanganga River At Muzaffarabad
2. Kunhar River At Naran
3. Kunhar River At G.H. Ullah
4. Jhelum River At Kohala

FIG 31

LAND SAT - 2 DERIVED SNOW COVER ESTIMATES MEASURED RUN OFF 1975 & 76.

LEGEND

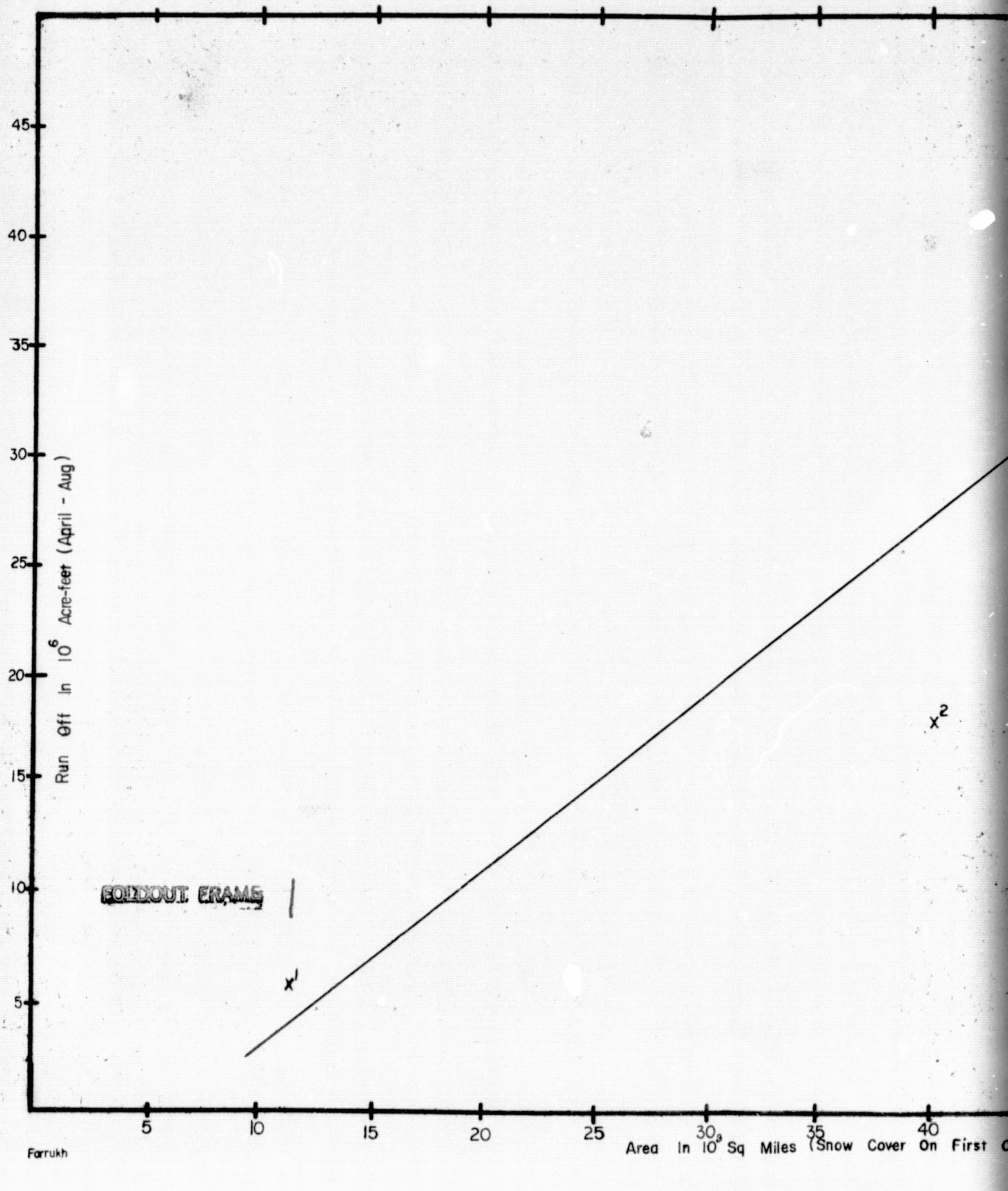
0 ------- 1975

X ------- 1976

2 FOLDOUT FRAME

7 8 9 10

Miles (Snow Cover On First Of April)


45
40
35
30
25
20
15
10
5
Run Off In 10^6 Acre-feet (April - Aug)
FOLDOUT FRAME
x^1
x^2
5
10
15
20
25
30
35
40
Area In 10^3 Sq Miles (Snow Cover On First
Farrukh

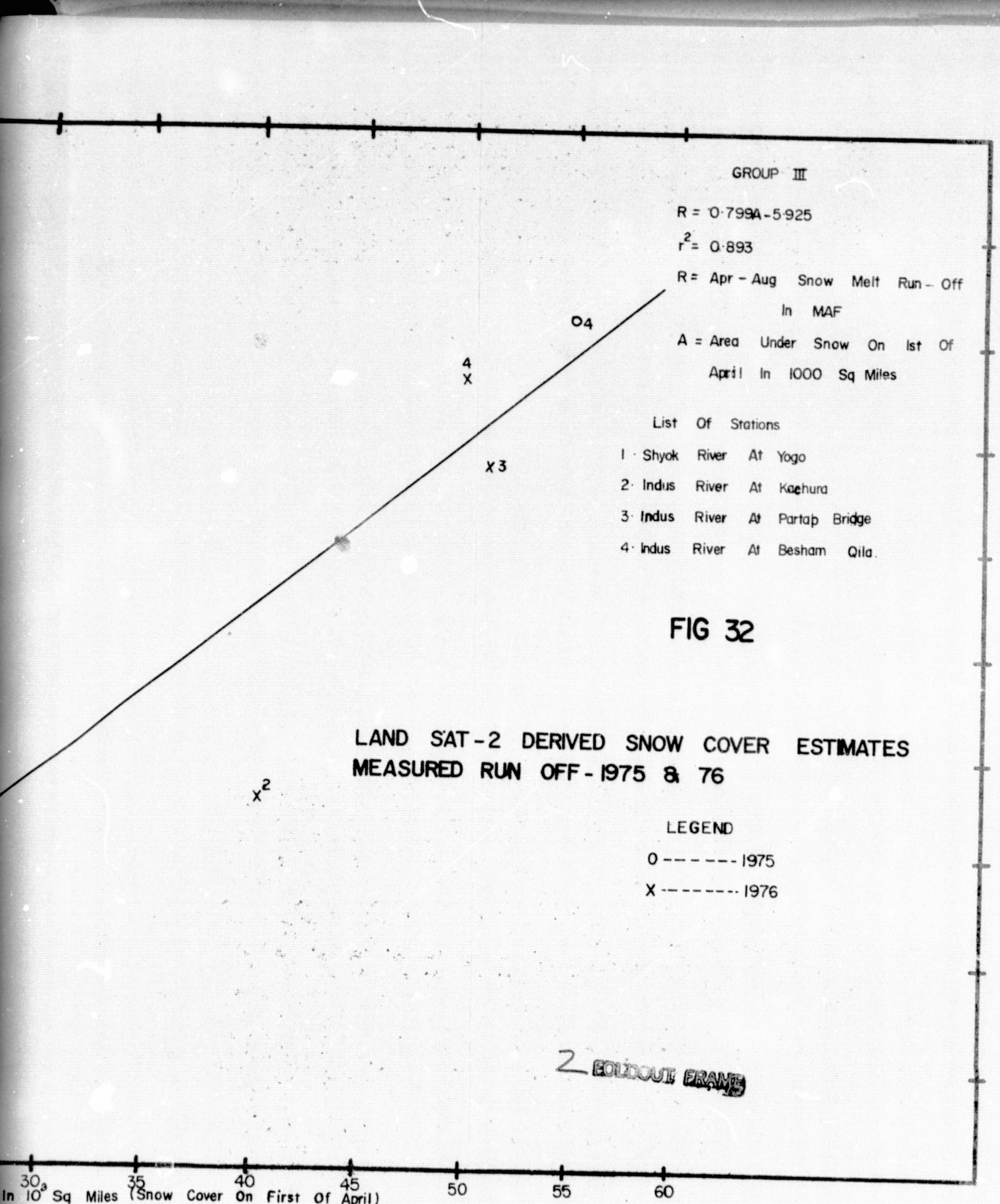


FIG 32

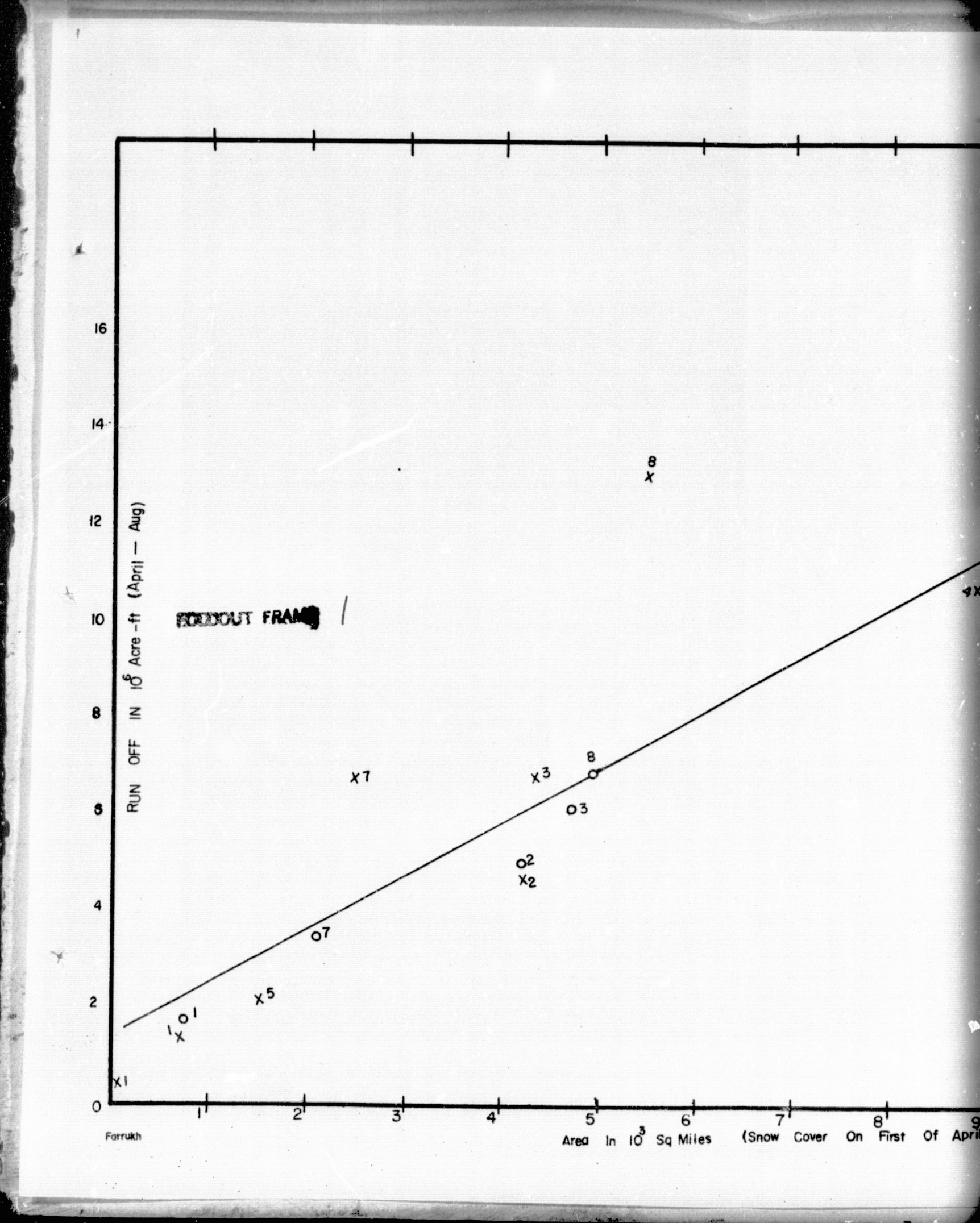
LAND SAT-2 DERIVED SNOW COVER ESTIMATES
MEASURED RUN OFF - 1975 & 76

LEGEND

0 ------ 1975

X ------- 1976

2 FOLDOUT FRAME


RUN OFF IN 10^6 Acre-ft (April — Aug)
Area In 10^3 Sq Miles (Snow Cover On First Of Apri
Farrukh
FOLDOUT FRAME
0
2
4
6
8
10
12
14
16
1
2
3
4
5
6
7
8
9
X1
O1
X5
O7
X7
X3
O3
O2
X2
X8

GROUP IV

$R = 1.355 + 1.140A$

$r^2 = 0.738$

R = Apr – Aug Snow Melt Run Off In MAF.

A = Area Under Snow On 1st Of April In 1000 Sq Miles

List Of Stations

1 - Swat River At Kalam

2 · Chitral River At Chitral

3 · Hunza River Dainyor Bridge

4 · Gilgit River At Alam Bridge

5 · Astore River At Doytan

6 · Kunhar River At Garhi Habib Ullah

7 · Kishanganga River At Muzaffarabad

8 · Jhelum River At Kohala

4X

04

FIG 33

LAND SAT - 2 DERIVED SNOW COVER ESTIMATES MEASURED RUN OFF 1975 &76

LEGEND

O ------ 1975

X ------ 1976

2 FOLDOUT FRAME

6 7 8 9 10 11

Miles (Snow Cover On First Of April)